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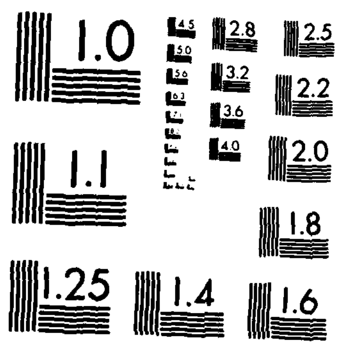

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1 May 1986

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Design and Evaluation of NUSC's Flow Loop Facility

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Naval Underwater Systems Center
Newport, Rhode Island / New London, Connecticut

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PREFACE

This report was prepared under Project No. A43117, "Characterization of Unsteady Viscous Fluid Flow," principal investigator P.J. Lefebvre (Code 8322). The work was sponsored under the Naval Underwater Systems Center's Independent Research Program.

The technical reviewer for this report was K.M. LaPointe (Code 8322).

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

A unique Flow Loop Facility capable of providing steady-state and user-defined transient flows (e.g., constant or exponential acceleration) was designed and built. Transient capabilities include acceleration of the flow to velocities of 30 ft/sec under accelerations up to 20 ft/sec^2 in circular test sections up to 6 inches in diameter. Provisions have been made for the future addition of larger test sections up to 12 inches in diameter with flows having accelerations up to 10 ft/sec^2 and velocities of 30 ft/sec. Tests showed that the entrance condition to a 2-inch-diameter test section had a velocity profile uniform within 1 percent and a maximum turbulence intensity of 1.31 percent.

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DESIGN AND EVALUATION OF NUSC'S FLOW LOOP FACILITY

INTRODUCTION

The Naval Underwater Systems Center's (NUSC) Flow Loop Facility, located in NUSC Building 1246, Newport, Rhode Island, was designed and built to support investigations of basic hydrodynamic and hydroacoustic phenomena under steady-state and transient flow conditions. The facility is unique in that it can provide programmed acceleration by means of a novel control system designed specifically for the Flow Loop Facility.

In general, the facility can provide flow rates up to 12,000 gallons/minute in circular test sections up to 12 inches in diameter. The unobstructed length of the test section is approximately 100 feet. Design requirements included accelerating flows with (1) velocities up to 30 ft/sec under constant accelerations to 20 ft/sec^2 in test sections up to 6 inches in diameter, and (2) velocities up to 30 ft/sec with constant accelerations of 10 ft/sec^2 for test section diameters greater than 6 inches and up to 12 inches. Because the facility was to be used for making very accurate boundary layer and acoustic measurements, stringent requirements and many constraints were imposed on its design.

Since the initial use of this facility was to be for hydrodynamic research, the major emphasis during its design was given to hydrodynamic requirements rather than to those for acoustic quieting. However, noise-reduction features were included where economically feasible. It was decided at the outset that, based on results of initial noise measurements, any necessary modifications could be made in the future.

This report describes the details of the design phase of the facility, the hardware, and the final verification tests conducted on a 2-inch-diameter test section.

DESIGN PHASE

DESIGN REQUIREMENTS

At the outset of the design phase, the following general operating and hardware requirements were established:

1. Test section to be isolated from:

   a. Structural vibrations (from pump, valves, discontinuities, etc.);

   b. Pressure pulsations (from pump, valves, water hammer, etc.); and

   c. Fluid-borne noise (disturbances).

2. System pressure rating: To withstand maximum static, transient, and water hammer pressures.

3. System pressures: Sufficiently high to prevent cavitation and liquid column separation.

4. Reservoir tank: Approximately 8000 gallons.

5. Heat exchanger: Sufficient capacity to maintain fluid temperatures between 68°F and 70°F.

6. Pump: Single variable speed, multiple parallel, or single with bypass lines used to accommodate range of test sections.

7. Upstream flow conditioner plenum: Flow management at entrance of test section (for range of test section diameters) with a turbulence intensity no greater than 0.5 percent and a flow profile within 1 percent of uniform.

8. Circular test sections: Up to 12 inches in diameter.

9. Accelerations:

   a. For test sections 6 inches in diameter and smaller - velocities up to 30 ft/sec with constant acceleration to 20 ft/sec^2; and

   b. For test sections greater than 6 inches and up to 12 inches in diameter - velocities to 30 ft/sec with constant acceleration to 10 ft/sec^2.

CONCEPTUAL DESIGN

Alden Research Laboratory (ARL) of Worcester Polytechnic Institute was contracted to develop a conceptual design that conformed to the specifications and requirements given above, starting from a preliminary facility layout developed by NUSC. ARL was tasked to (1) develop a transient analysis computer program for use in optimizing the design; (2) derive required valve and pump characteristics to cover the desired range of test line sizes and accelerations; and (3) calculate the nozzle shape upstream of the test section necessary to meet the entrance flow requirements.

The computer program for transient analysis was based on the state-of-the-art method of characteristics and was developed from a basic program already available at ARL. Using the computer program, an analysis was conducted to determine:

1. Desired pump characteristics.

2. Desired control valve characteristics (C_V versus time).

3. Effect of minimum (2-inch diameter) and maximum test section diameters on pump and control valve characteristics.

4. Possibility of cavitation and required initial pressure to avoid cavitation.

5. Pump combination/speed for minimum and maximum test section line sizes.

6. Return line size.

7. Pressure distribution throughout the facility.

The appendix documents the more important results of the ARL design study, including a block diagram of the design to which the transient analysis was applied. Even though pipe lengths and various other features have been changed in the final design, the modifications were relatively minor, and the computer-generated data are generally applicable to the final design.

The remaining illustrations in the appendix are self-explanatory and provide the following information:

1. Required pump characteristics.

2. Control valve characteristics versus test section diameter.

3. Pressure distribution in the facility during acceleration.

4. Pressure distribution during valve closure.

The information contained in the appendix is useful when employing a different diameter test section.

DETAILED DESIGN

In general, the final design follows the conceptual design and design requirements. The facility can accommodate up to 12-inch-diameter test sections and control valve sections. Mating piping to these sections consists of 12-inch, 150-pound flanges. For piping smaller than 12 inches in diameter, appropriate reducers and expanders are required on the ends of the sections.

Drawings for the detailed design were assigned NAVFAC drawing numbers 2088491 through 2088502. Figure 1 shows the major features of the final design. Not shown is a controlled environment instrumentation room located at the downstream end of the test section. The test section runs through this room, which houses the laser Doppler velocimeter (LDV) and most of the instrumentation and data acquisition hardware.

Figure 2 is a plan view showing the general location of the major components of the facility at NUSC. Note that the reservoir and pumps, located in the tow tank filter room, are physically isolated from the test section, which is located in the main laboratory area. The tow tank filter room is approximately 15 feet below the main laboratory floor.

The following paragraphs describe the major features of the facility, starting at the upstream end and proceeding downstream in the flow direction. For the most part, the facility is fabricated of stainless steel components.

The stainless steel reservoir rests on the lower level of the filter room and extends through the first floor level for a total height of approximately 31.5 feet. The return line is located 6 feet below the water level to ensure a constant back pressure at the test section, and to reduce the possibility of agitating the water surface and entrapping air in the water. The centerline of the pipe that feeds the pumps is approximately 2.6 feet above the lower level of the filter room. The 28 feet of head above the pumps is more than adequate to ensure a positive gage pressure everywhere in the pump suction line, thereby precluding the possibility of taking in any outside air.

The two pumps, 150 hp and 300 hp, conform to the pump characteristics suggested in the conceptual study. The 150-hp pump is for test section diameters up to 6 inches, while the 300-hp pump is for test section diameters up to 12 inches. Both pumps are bronze-fitted constant-speed pumps. All-bronze pumps were chosen because of cost considerations and previous success using a bronze-fitted pump in NUSC's Water Tunnel Facility. Drains are located at the bottom of each pump to allow periodic removal of discolored water.

The curves for the 150-hp Crane-Deming pump are shown in figure 3, and those for the 300-hp Allis-Chalmers pump in figure 4. Vibration isolators are located on both sides of the 150-hp pump. Piping for the 300-hp pump has not yet been installed. Installation will be completed in the future when one of the larger test sections is used.

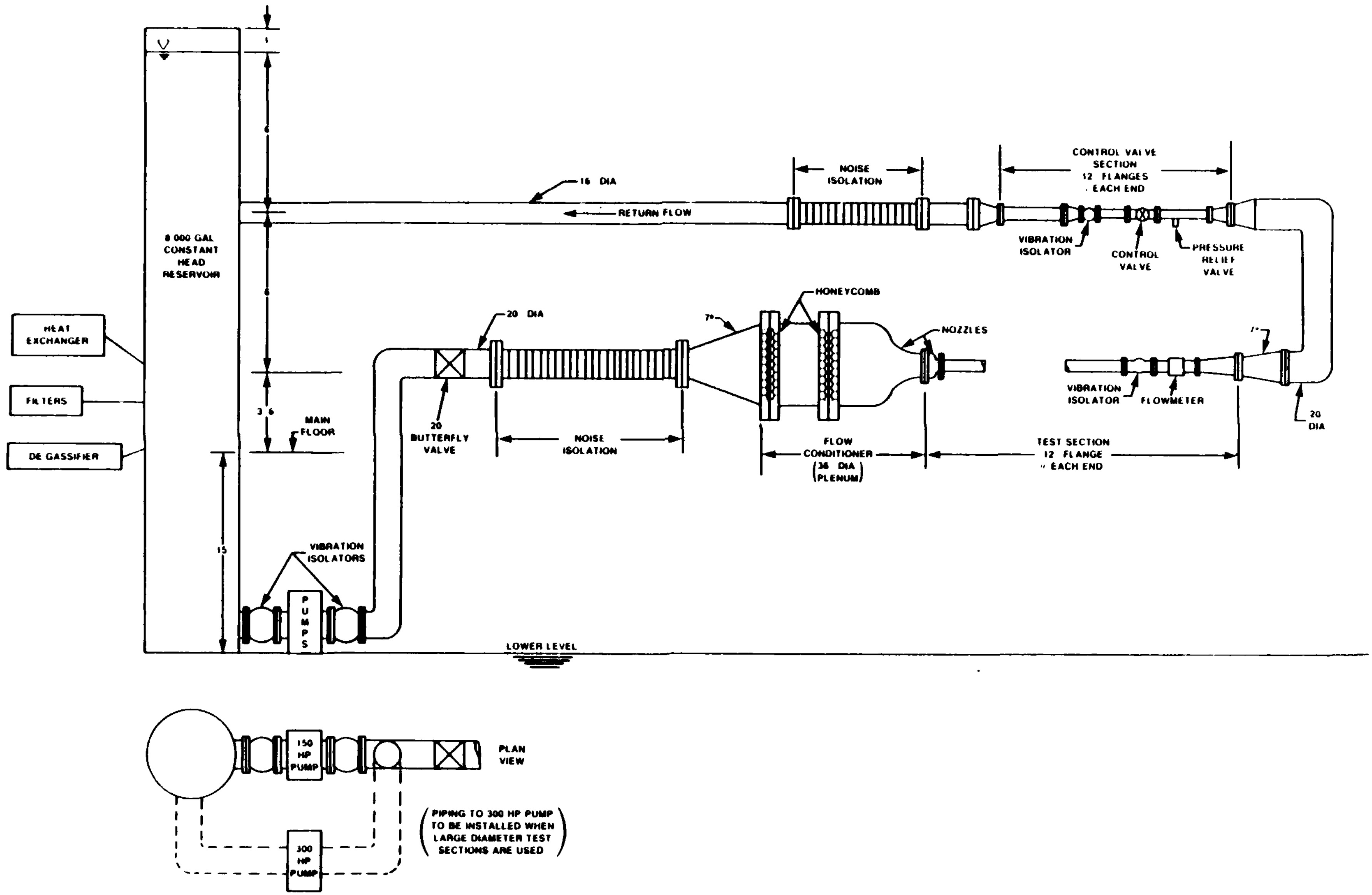


Figure 1. Flow Loop Facility Layout

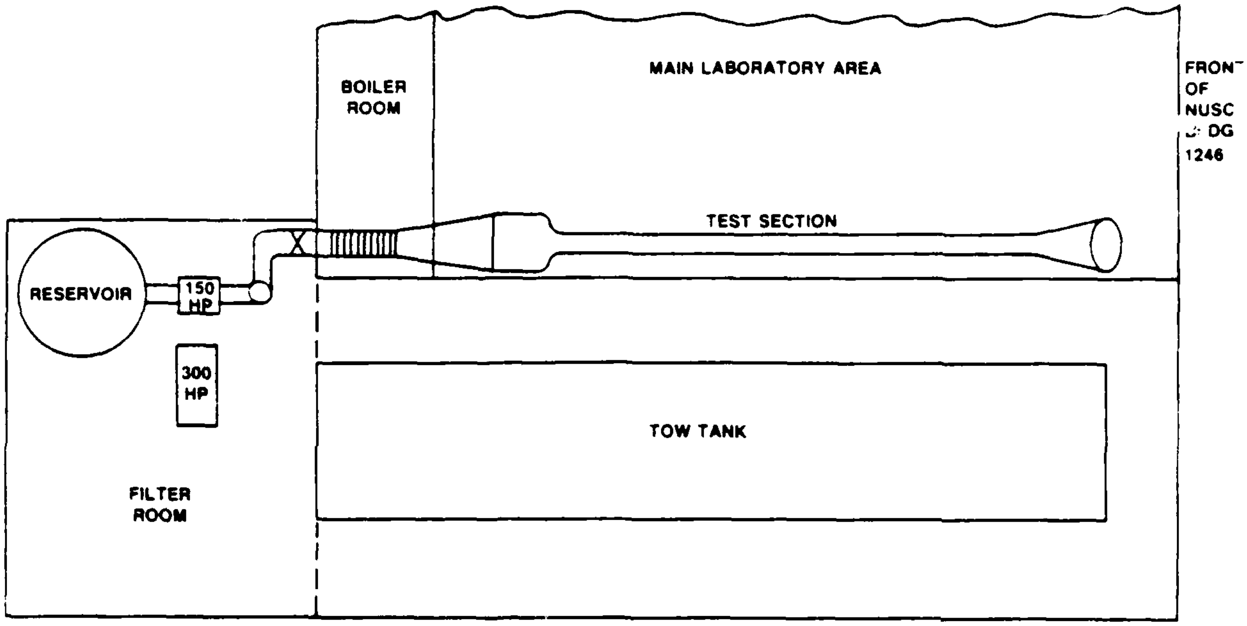


Figure 2. Location of Flow Loop Facility

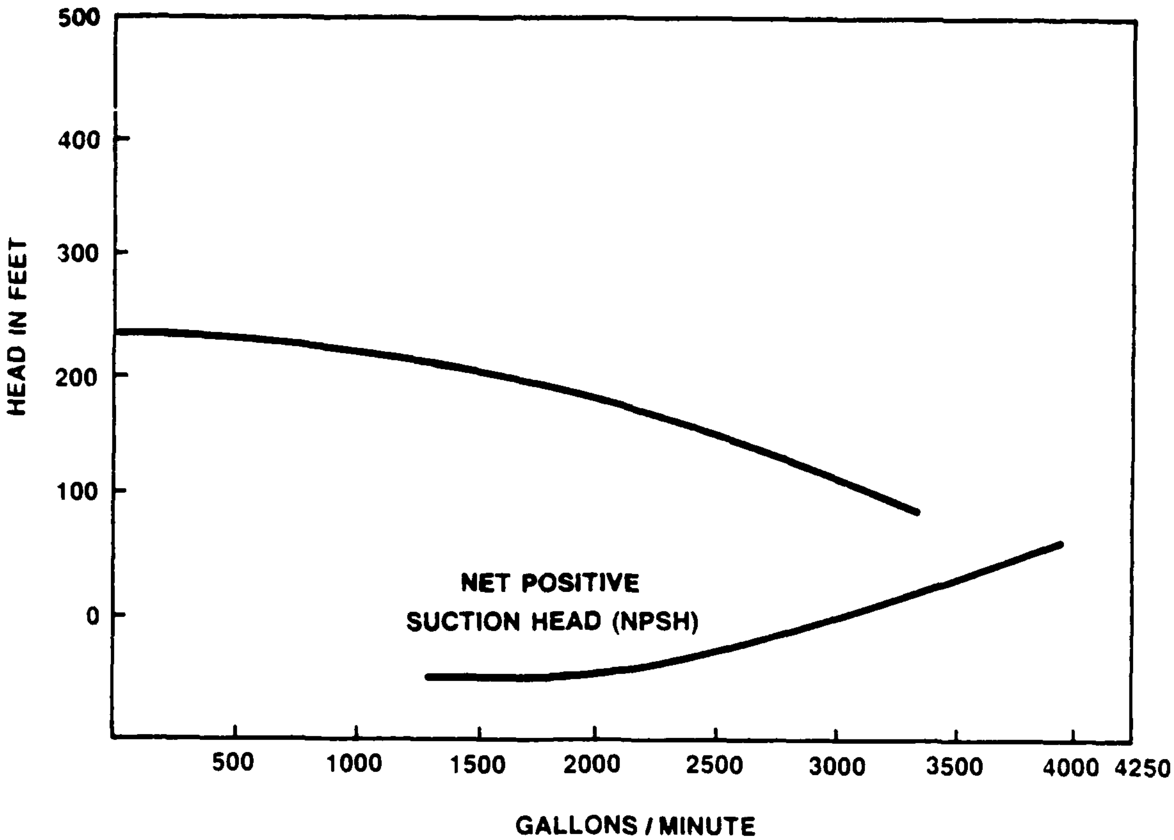


Figure 3. Pump Curves for 150-hp Pump

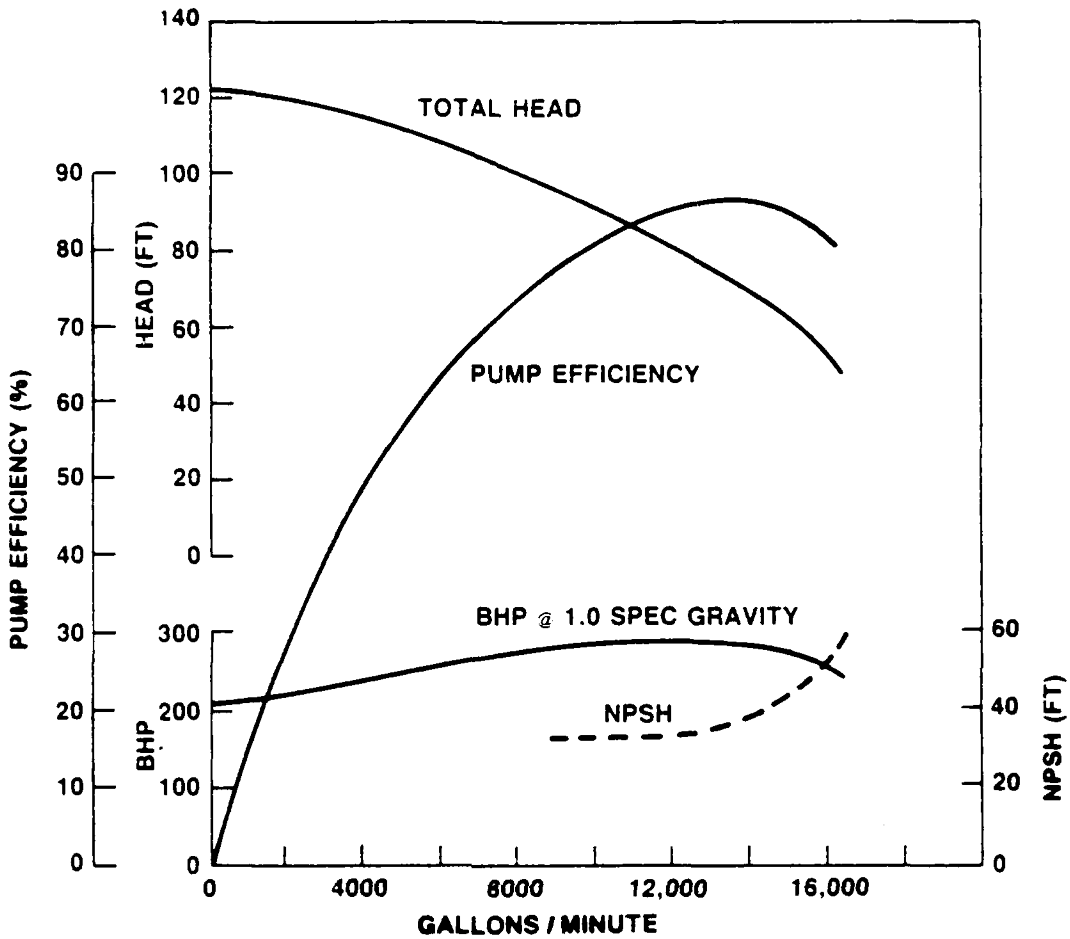


Figure 4. Pump Curves for 300-hp Pump

Low-voltage starters are provided for each pump. Electrical connections to the pumps are such that only one pump can operate at any one time. In addition, the pumps will shut off if the reservoir water level drops to within 6.5 feet of the pump centerline. On/off switches are located near the pumps and in the instrumentation room.

A 2-inch bypass line has been installed between the discharge piping and the reservoir to ensure that the water temperature in the vicinity of the pump does not rise to unacceptable levels during pump stall. Pump stall will be imposed prior to any accelerating flow test that starts from zero flow. In this case, the facility control valve will be closed prior to a test run until the pump attains operating speed.

A pneumatically actuated 20-inch-diameter stainless steel butterfly valve is located after the pumps. The control is located in the instrumentation room. The valve has been adjusted to close over a 15-second duration to preclude water-hammer effects possible under quick valve closure.

Noise isolation sections are located in the feed and return lines. The length of each is 10 pipe diameters. A 20-inch-diameter rubber hose is used in the feed line and a 16-inch-diameter rubber hose is used in the return line. The hoses, helical wire reinforced, are commercially available.

Immediately following the upstream noise isolation section is a 7° expander from the 20-inch line to the 35.25-inch diameter of the plenum chamber. The 7° angle was chosen to inhibit any large-scale separation.

A 36-inch-diameter flow conditioner plenum, shown in figure 5, follows the noise isolation section. The two welded, stainless steel, honeycomb sections are sandwiched in 37-inch-diameter counterbores that were machined into the mating flanges. The honeycomb sections are 6-inches long and their cell size is 3/8 inch. A gasket holds the honeycomb against the downstream flange. A specially designed nozzle was welded to the downstream end of the 35.25-inch (inside diameter) straight section of the plenum.

Hydrodynamic design of the flow conditioning plenum was based on the requirement for a uniform velocity profile within 1 percent and a turbulence intensity of less than 0.5 percent. The nozzle was designed to avoid flow separations and to ensure the 1-percent uniform flow profile. Pressures and velocities along the nozzle were determined by potential flow theory, and any separation of the boundary layer was checked using Stratford's criteria (reference 1). Two fifth-order polynomials were ultimately used to define the shape. The equations are:

For $0 \leq X \leq 18$ inches:

$$R = 18 - \left\{ 8\left(\frac{X}{18}\right)^3 \left[3.25 - 3.1875\left(\frac{X}{18}\right) + 0.9375\left(\frac{X}{18}\right)^2\right] \right\} .$$

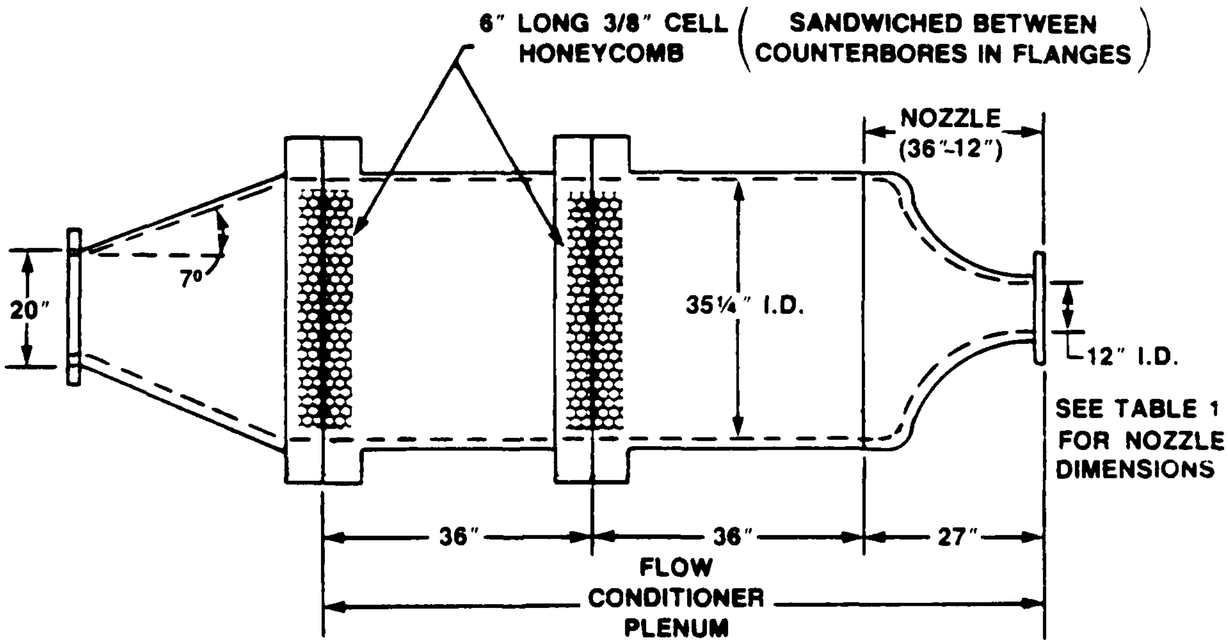


Figure 5. Flow Conditioner Plenum

For X > 18 inches:

$$R = 6 + \left\{\left(10 - \frac{1}{L}\right)\left(\frac{L-X}{L-18}\right)^3\left[10 - \frac{3(L-X)}{4} + \left(\frac{L-X}{L-18}\right)\left(\frac{5.25(L-X)}{4} - 15\right)\right.\right.$$
$$\left.\left. + \left(\frac{L-X}{L-18}\right)^2\left(6 - \frac{2.25(L-X)}{4}\right)\right]\right\}.$$

In these equations, X is the axial distance starting at R = 18 inches, R is the nozzle radius, and L is 36 inches.

Table 1 is a listing of the actual dimensions to which the nozzle was built. Radial dimensions were held within ± 0.015 inch. The nozzle, made of 316 stainless steel, was fabricated by the spinning method. Note that since the nozzle starts with a diameter of 35.25 inches and not 36 inches, the value of X from table 1 at the beginning of the nozzle is X = 4.00.

Turbulence attenuation from the nozzle contraction and the honeycomb sections resulted in a calculated turbulence intensity of less than 0.5 percent at the exit of the 12-inch-diameter end of the nozzle. Calculations of turbulence attenuation were based on the method presented by Lumley and McMahon (reference 2).

The test section that follows the plenum is approximately 100-feet long and can accommodate pipe sizes up to 12 inches. A 2-inch-diameter test section, shown in figure 6, was built for the facility evaluation. This test section consists of (1) a nozzle from the 12-inch diameter of the plenum down to the 2-inch diameter of the test section; (2) six 16.4-feet-long stainless steel pipe lengths having extremely close machining tolerances as listed in figure 6; (3) a clear section of cast acrylic; (4) a vibration isolator; (5) a transient flowmeter and; (6) a 7° expander from 2 inches to 12 inches.

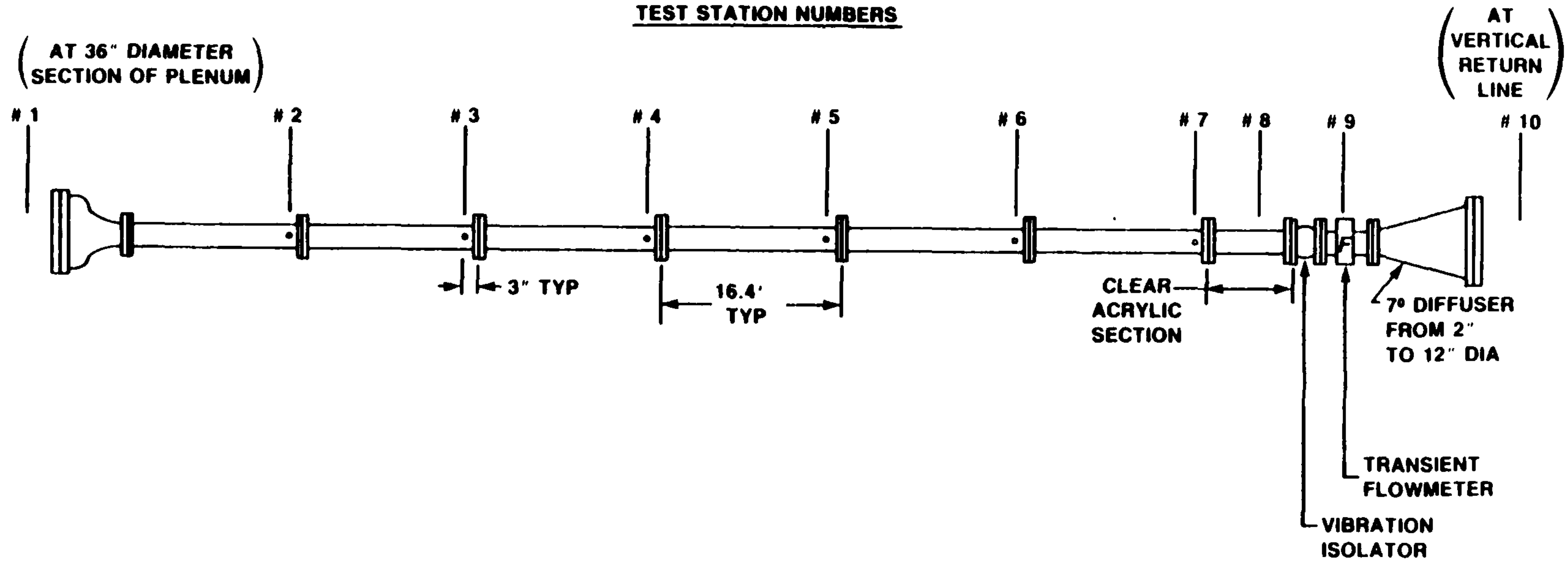
The nozzle was designed according to the procedure used for the plenum nozzle to ensure a 1-percent uniform velocity profile with no separation. The equation for its shape is:

$$R = 6 - \left\{\left(6 - R_2\right)\left(\frac{X}{12}\right)^3\left[10 - \frac{15X}{12} + 6\left(\frac{X}{12}\right)^2\right]\right\},$$

where R_2 is the radius at the nozzle exit, and X is the axial distance starting at R = 6 inches.

This equation is valid for test sections down to a 2-inch diameter. Values of R versus X are tabulated in table 2 for nozzle exit diameters of 2, 4, 6, 8, and 10 inches. Because of the additional contraction beyond the 12-inch diameter, the calculated turbulence intensity is less than the 0.5 percent calculated for the end of the 12-inch-diameter plenum nozzle.

The clear test section provides a means by which LDV measurements can be made. The transient flowmeter, designed and built by NUSC, monitors volumetric flow rates versus time, and also provides the feedback signal for the control system that gives programmed acceleration. Details of the flowmeter design, fabrication, and evaluation are presented in reference 3.



PHYSICAL SPECIFICATIONS
1. INSIDE DIAMETER = 2 $\pm$ .001 INCHES
2. INSIDE SURFACE FINISH = 16μ-INCHES
3. MATING AT FLANGES WITHIN .001 INCH
4. O-RING FACE SEAL AT FLANGES (NO HORIZONTAL GAP AT FLANGES)

STATION	INSTRUMENTATION
1	FLUSH PRESSURE SENSOR
2 - 7	PRESSURE TAP/FLUSH PRESSURE SENSOR/SURFACE SHEAR STRESS SENSOR
8	LASER DOPPLER VELOCIMETER
9	TRANSIENT FLOWMETER
10	TEMPERATURE PROBE

Figure 6. Two-Inch-Diameter Test Section

Table 1. Dimensions for 36-Inch to 12-Inch Nozzle

X	R	X	R	X	R
0.00	18.0000	10.00	15.6858	20.00	8.6914
0.20	18.0000	10.20	15.5740	20.20	8.6669
0.40	18.0000	10.40	15.4601	20.40	8.4233
0.60	17.9997	10.60	15.3440	20.60	8.2938
0.80	17.9991	10.80	15.2258	20.80	8.1674
1.00	17.9978	11.00	15.1056	21.00	8.0444
1.20	17.9958	11.20	14.9834	21.20	7.9248
1.40	17.9928	11.40	14.8594	21.40	7.8088
1.60	17.9887	11.60	14.7335	21.60	7.6966
1.80	17.9833	11.80	14.6059	21.80	7.5881
2.00	17.9765	12.00	14.4766	22.00	7.4835
2.20	17.9681	12.20	14.3457	22.20	7.3827
2.40	17.9580	12.40	14.2132	22.40	7.2859
2.60	17.9461	12.60	14.0793	22.60	7.1931
2.80	17.9323	12.80	13.9440	22.80	7.1043
3.00	17.9164	13.00	13.8074	23.00	7.0195
3.20	17.8983	13.20	13.6695	23.20	6.9387
3.40	17.8781	13.40	13.5305	23.40	6.8619
3.60	17.8554	13.60	13.3903	23.60	6.7890
4.80	17.8304	13.80	13.2491	23.80	6.7201
4.00	17.8029	14.00	13.1069	24.00	6.6550
4.20	17.7728	14.20	12.9638	24.20	6.5938
4.40	17.7401	14.40	12.8199	24.60	6.4824
4.60	17.7047	14.60	12.6752	24.80	6.4322
4.80	17.6666	14.80	12.5298	25.00	6.3854
5.00	17.6258	15.00	12.3837	25.20	6.3421
5.20	17.5821	15.20	12.2371	25.40	6.3021
5.40	17.5357	15.40	12.0899	25.60	6.2653
5.60	17.4863	15.60	11.9422	25.80	6.2315
5.80	17.4341	15.80	11.7942	26.00	6.2008
6.00	17.3790	16.00	11.6457	26.20	6.1728
6.20	17.3210	16.20	11.4969	26.40	6.1476
6.40	17.2601	16.40	11.3479	26.60	6.1250
6.60	17.1962	16.60	11.1986	26.80	6.1048
6.80	17.1295	16.80	11.0491	27.00	6.0870
7.00	17.0599	17.00	10.8995	27.20	6.0713
7.20	16.9874	17.20	10.7497	27.40	6.0576
7.40	16.9120	17.40	10.5999	27.60	6.0459
7.60	16.8338	17.60	10.4499	27.80	6.0358
7.80	16.7527	17.80	10.3000	28.00	6.0274
8.00	16.6689	18.00	10.1500	28.20	6.0204
8.20	16.5823	18.20	10.0000	28.40	6.0148
8.40	16.4930	18.40	9.8501	28.60	6.0103
8.60	16.4010	18.60	9.7005	28.80	6.0068
8.80	16.3064	18.80	9.5517	29.00	6.0043
9.00	16.2092	19.00	9.4039	29.20	6.0024
9.20	16.1094	19.20	9.2575	29.40	6.0012
9.40	16.0071	19.40	9.1128	29.60	6.0005
9.60	15.9024	19.60	8.9701	29.80	6.0002
9.80	15.7952	19.80	8.8295	30.00	6.0000

X = Axial Distance; R = Inside Radius.

Table 2. Dimensions for Nozzles from 12 Inches to Various Test Section Diameters

X	$R_{2"}$	$R_{4"}$	$R_{6"}$	$R_{8"}$	$R_{10"}$
0.00	6.0000	6.0000	6.0000	6.0000	6.0000
0.10	6.0000	6.0000	6.0000	6.0000	6.0000
0.20	5.9998	5.9998	5.9999	5.9999	6.0000
0.30	5.9992	5.9994	5.9995	5.9997	5.9998
0.40	5.9982	5.9986	5.9989	5.9993	5.9996
0.50	5.9966	5.9973	5.9980	5.9986	5.9993
0.60	5.9942	5.9954	5.9965	5.9977	5.9988
0.70	5.9909	5.9927	5.9946	5.9964	5.9982
0.80	5.9866	5.9893	5.9920	5.9947	5.9973
0.90	5.9812	5.9850	5.9887	5.9925	5.9962
1.00	5.9746	5.9796	5.9847	5.9898	5.9949
1.10	5.9666	5.9733	5.9800	5.9866	5.9933
1.20	5.9572	5.9658	5.9743	5.9829	5.9914
1.30	5.9463	5.9570	5.9678	5.9785	5.9893
1.40	5.9338	5.9471	5.9603	5.9735	5.9868
1.50	5.9197	5.9358	5.9518	5.9679	5.9839
1.60	5.9039	5.9231	5.9424	5.9616	5.9808
1.70	5.8863	5.9091	5.9318	5.9545	5.9773
1.80	5.8669	5.8936	5.9202	5.9468	5.9734
1.90	5.8457	5.8765	5.9074	5.9383	5.9691
2.00	5.8225	5.8580	5.8935	5.9290	5.9645
2.10	5.7974	5.8380	5.8785	5.9190	5.9595
2.20	5.7704	5.8163	5.8622	5.9082	5.9541
2.30	5.7414	5.7931	5.8448	5.8966	5.9483
2.40	5.7104	5.7683	5.8262	5.8842	5.9421
2.50	5.6774	5.7419	5.8064	5.8710	5.9355
2.60	5.6424	5.7139	5.7854	5.8570	5.9285
2.70	5.6054	5.6843	5.7632	5.8422	5.9211
2.80	5.5664	5.6531	5.7398	5.8266	5.9133
2.90	5.5254	5.6203	5.7152	5.8102	5.9051
3.00	5.4824	5.5859	5.6895	5.7930	5.8965
3.10	5.4375	5.5500	5.6625	5.7750	5.8875
3.20	5.3907	5.5125	5.6344	5.7563	5.8781
3.30	5.3419	5.4735	5.6051	5.7368	5.8684
3.40	5.2913	5.4330	5.5748	5.7165	5.8583
3.50	5.2388	5.3911	5.5433	5.6955	5.8478
3.60	5.1846	5.3477	5.5108	5.6738	5.8369
3.70	5.1286	5.3029	5.4772	5.6514	5.8257
3.80	5.0709	5.2567	5.4425	5.6284	5.8142
3.90	5.0116	5.2093	5.4069	5.6046	5.8023
4.00	4.9506	5.1605	5.3704	5.5802	5.7901
4.10	4.8881	5.1105	5.3329	5.5553	5.7776
4.20	4.8242	5.0593	5.2945	5.5297	5.7648

Table 2. Dimensions for Nozzles from 12 Inches to Various Test Section Diameters (Cont'd)

X	$R_{2"}$	$R_{4"}$	$R_{6"}$	$R_{8"}$	$R_{10"}$
4.30	4.7588	5.0070	5.2553	5.5035	5.7518
4.40	4.6920	4.9536	5.2152	5.4768	5.7384
4.50	4.6240	4.8992	5.1744	5.4496	5.7248
4.60	4.5547	4.8438	5.1328	5.4219	5.7109
4.70	4.4843	4.7874	5.0906	5.3937	5.6969
4.80	4.4128	4.7302	5.0477	5.3651	5.6826
4.90	4.3403	4.6723	5.0042	5.3361	5.6681
5.00	4.2669	4.6135	4.9601	5.3068	5.6534
5.10	4.1926	4.5541	4.9156	5.2771	5.6385
5.20	4.1176	4.4941	4.8706	5.2471	5.6235
5.30	4.0419	4.4335	4.8252	5.2168	5.6084
5.40	3.9656	4.3725	4.7794	5.1863	5.5931
5.50	3.8888	4.3111	4.7333	5.1555	5.5778
5.60	3.8116	4.2493	4.6869	5.1246	5.5623
5.70	3.7340	4.1872	4.6404	5.0936	5.5468
5.80	3.6561	4.1249	4.5937	5.0625	5.5312
5.90	3.5781	4.0625	4.5469	5.0312	5.5156
6.00	3.5000	4.0000	4.5000	5.0000	5.0000
6.10	3.4219	3.9375	4.4531	4.9688	5.4844
6.20	3.3439	3.8751	4.4063	4.9375	5.4688
6.30	3.2660	3.8128	4.3596	4.9064	5.4532
6.40	3.1884	3.7507	4.3131	4.8754	5.4377
6.50	3.1112	3.6889	4.2667	4.8445	5.4222
6.60	3.0344	3.6275	4.2206	4.8137	5.4069
6.70	2.9581	3.5665	4.1748	4.7832	5.3916
6.80	2.8824	3.5059	4.1294	4.7529	5.3765
6.90	2.8074	3.4459	4.0844	4.7229	5.3615
7.00	2.7331	3.3865	4.0399	4.6932	5.3466
7.10	2.6597	3.3278	3.9958	4.6639	5.3319
7.20	2.5872	3.2698	3.9523	4.6349	5.3174
7.30	2.5157	3.2126	3.9094	4.6063	5.3031
7.40	2.4453	3.1562	3.8672	4.5781	5.2891
7.50	2.3760	3.1008	3.8256	4.5504	5.2752
7.60	2.3080	3.0464	3.7848	4.5232	5.2616
7.70	2.2412	2.9930	3.7447	4.4965	5.2482
7.80	2.1758	2.9407	3.7055	4.4703	5.2352
7.90	2.1119	2.8895	3.6671	4.4447	5.2224
8.00	2.0494	2.8395	3.6296	4.4198	5.2099
8.10	1.9884	2.7907	3.5931	4.3954	5.1977
8.20	1.9291	2.7433	3.5575	4.3716	5.1858
8.30	1.8714	2.6971	3.5228	4.3486	5.1743
8.40	1.8154	2.6523	3.4892	4.3262	5.1631
8.50	1.7612	2.6089	3.4567	4.3045	5.1522

Table 2. Dimensions for Nozzles from 12 Inches to Various Test Section Diameters (Cont'd)

X	$R_{2''}$	$R_{4''}$	$R_{6''}$	$R_{8''}$	$R_{10''}$
8.60	1.7087	2.5670	3.4252	4.2835	5.1417
8.70	1.6581	2.5265	3.3949	4.2632	5.1316
8.80	1.6093	2.4875	3.3656	4.2437	5.1219
8.90	1.5625	2.4500	3.3375	4.2250	5.1125
9.00	1.5176	2.4141	3.3105	4.2070	5.1035
9.10	1.4746	2.3797	3.2848	4.1898	5.0949
9.20	1.4336	2.3469	3.2602	4.1734	5.0867
9.30	1.3946	2.3157	3.2368	4.1578	5.0789
9.40	1.3576	2.2861	3.2146	4.1430	5.0715
9.50	1.3226	2.2581	3.1936	4.1290	5.0645
9.60	1.2896	2.2317	3.1738	4.1158	5.0579
9.70	1.2586	2.2069	3.1552	4.1034	5.0517
9.80	1.2296	2.1837	3.1378	4.0918	5.0459
9.90	1.2026	2.1620	3.1215	4.0810	5.0405
10.00	1.1775	2.1420	3.1065	4.0710	5.0355
10.10	1.1543	2.1235	3.0926	4.0617	5.0309
10.20	1.1331	2.1064	3.0798	4.0532	5.0266
10.30	1.1137	2.0909	3.0682	4.0455	5.0227
10.40	1.0961	2.0769	3.0576	4.0384	5.0192
10.50	1.0803	2.0642	3.0482	4.0321	5.0161
10.60	1.0661	2.0529	3.0397	4.0265	5.0132
10.70	1.0537	2.0430	3.0322	4.0215	5.0107
10.80	1.0428	2.0342	3.0257	4.0171	5.0086
10.90	1.0334	2.0267	3.0200	4.0134	5.0067
11.00	1.0254	2.0204	3.0153	4.0102	5.0051
11.10	1.0188	2.0150	3.0113	4.0075	5.0338
11.20	1.0134	2.0107	3.0080	4.0053	5.0027
11.30	1.0091	2.0073	3.0054	4.0036	5.0018
11.40	1.0058	2.0046	3.0035	4.0023	5.0012
11.50	1.0034	2.0027	3.0020	4.0014	5.0007
11.60	1.0018	2.0014	3.0011	4.0007	5.0004
11.70	1.0007	2.0006	3.0004	4.0003	5.0002
11.80	1.0002	2.0002	3.0001	4.0001	5.0000
11.90	1.0000	2.0000	3.0000	4.0000	5.0000

The control valve section is separated from the test section by a 6-foot-high vertical run of 20-inch-diameter pipe. The control valve section is long enough to accept a 12-inch valve with 10 pipe diameters upstream and 5 pipe diameters downstream of 12-inch diameter pipe. There are 12-inch, 150-pound mating flanges on both ends of this section.

Valve sizes and characteristics that are required for various test section diameters are presented in the appendix. For the present 2-inch-diameter test section, a 3-inch control valve was required. A Masoneillon anti-cavitation, anti-noise cage control valve was selected. Upstream of the valve is a 12-inch to 3-inch reducer, followed by a straight section of 3-inch pipe that contains a 2-inch pressure relief valve as a measure against potential damage from water hammer effects. The linkage for the control valve actuator is mounted on a permanent shelf located directly below the return pipe line. The shelf length can accommodate the linkage that will be required for control valves up to 12 inches in diameter. Details of the feedback control system are given in reference 4.

Downstream of the control valve section is the previously discussed noise isolation section, followed by a 16-inch-diameter stainless steel return line to the reservoir.

Wherever possible between the upstream noise isolation section and the vibration isolator in the test section, pipe supports were fitted with rubber pads inserted between the pipe and the support to isolate any structural vibrations. The only location where a direct connection from a support to the piping was allowed was at the first flange of the plenum. This was required since the support had to resist the large horizontal force and resulting moment at the plenum due to different flow areas between the plenum's inlet and outlet.

Conditioning of the water is provided by a heat exchanger, filters, and a degassifier. The heat exchanger was designed to maintain water temperature within ± 2°F of the set temperature. Reservoir water is circulated through offline stainless steel shell and tube chillers that use Freon delivered from a 25-ton Dunham-Bush condenser unit. The filtering system provides filtering capabilities between 0.5 and 25 microns. The filters are manufactured by CUNO Incorporated. The degassifier removes dissolved air and gases in the reservoir water down to a vacuum of 29 inches of mercury. The system is manufactured by Union Kol-Flo Corporation. Controls for each of the three water conditioning units are located near the 20-inch butterfly valve.

FACILITY EVALUATION

The main objective of the evaluation was to establish the hydrodynamic characteristics existing in the facility. The hydrodynamic parameters presented here are the entrance flow conditions (mean velocity profile and turbulence intensity) to the 2-inch-diameter test section and the spectrum of the wall pressure at station 7 of the test section. This information is also intended as an aid to future users of the facility in predicting the performance for test sections other than the present 2-inch-diameter section.

Other hydrodynamic characteristics such as the pressure gradient (shear stress) along the test section and the fully developed profile (including turbulence characteristics) are valid only for the test section currently installed. Therefore, these data will be presented in a future report describing results from the first set of experiments to be conducted in the facility under the ongoing NUSC independent research project "Characterization of Unsteady Viscous Fluid Flow."

Since the facility will be used in the future for hydroacoustic studies, some effort was spent in obtaining structureborne vibration spectra. This information will be used as a basis for incorporating future additional structural noise isolation devices.

ENTRANCE FLOW CONDITIONS

Mean velocity profile and turbulence intensity were measured at an axial location 3 inches from the start of the 2-inch-diameter test section. A Thermal Systems Incorporated (TSI) miniature, hot-film, straight probe was used, along with a TSI hot-film anemometer, dc voltmeter, and rms voltmeter.

In order to use an uncalibrated hot-film probe, the intercept method was applied to calculate the flow profile. The equations used were:

Non-dimensional mean velocity:

$$\frac{\bar{V}_p}{\bar{V}_{C_L}} = \left(\frac{E_p^2 - E_o^2}{E_{C_L}^2 - E_o^2}\right)^2 .$$

Turbulence intensity:

$$\frac{\sqrt{\overline{v_p^2}}}{\bar{V}_p} = \frac{4E_p^2}{E_p^2 - E_o^2} \, \frac{\sqrt{\overline{e_p^2}}}{E_p} .$$

These equations are based on

$$\bar{V}_p = c\left(\bar{E}_p^2 - \bar{E}_o^2\right)^2 ,$$

where V is the mean velocity; $\sqrt{\overline{v_p^2}}$ is the rms of the velocity fluctuations; $\bar{E}$ is the mean voltage output from the hot-film anemometer; $\sqrt{\overline{e_p^2}}$ is the rms of the voltage fluctuations; and the subscripts C_L, o, and p refer to centerline position, no flow, and point of measurement, respectively.

Considering the fact that the calibration curve for hot-film probes in the water flow of a circulating loop changes almost continuously with time, the above approach was considered the most accurate and easiest to implement. The accuracy was estimated at ±1 percent for the conditions encountered in the present measurements.

Measurements were made in one plane of the test section at increments of 0.05 inch from the inner wall to the pipe centerline and additionally at 1.1, 1.2, and 1.3 inches from the inner wall. Mean pipe flow velocities at which measurements were made were 2 and 8 ft/sec. Vibrations of the hot-film probe precluded measurements above 8 ft/sec.

Results showed that the mean velocity profiles were within 1 percent of uniform. However, since the accuracy of the measurements was estimated at ±1 percent, the profiles are considered uniform within ±1 percent.

Measurements of turbulence intensity (non-dimensionalized with the mean velocity at the point of measurement) were approximately constant over the pipe radius. For the 8-ft/sec velocity, turbulence intensity was between 0.72 and 0.83 percent; for the 2-ft/sec velocity, turbulence intensity ranged from 1.15 to 1.31 percent.

On examining the signal from the hot-film anemometer on an oscilloscope, a low-level sinusoidal signal at approximate 20 Hz was superimposed on the dc level. Spectra presented in the next section indicate that this noise is from the pump and is at 23.5 Hz. Even with this noise, the entrance conditions are acceptable, although somewhat higher than expected. Future modifications to reduce structural vibrations may contribute to a reduction in the turbulence intensity levels presented here.

PRESSURE SPECTRA

Spectra were obtained using the output of the flush-mounted pressure transducer located at station 7. The transducer was a Kulite model XTM-190-100 that had a metal diaphragm with a diameter of 0.150 inch. Conditions at which spectra were obtained included no flow with the pump running and nominal mean velocities of 4, 16, and 30 ft/sec.

Results for each of the spectra showed only negligible differences for the various test conditions and flows. Therefore, only the results for the 16-ft/sec test are presented in figure 7. Spectra are presented as dB//1 psi/Hz versus frequency for three ranges: 0-200 Hz, 0-500 Hz, and 0-10,000 Hz. Bandwidth is labeled BW and ordinate (X) and abscissa (Y) values are given for the one point on each spectra marked with an X. In the bottom spectrum of figure 7, two peaks are observed at the low frequency end. They are at 23.5 and 43.5 Hz and are associated with pump noise. However, the pressure levels over the entire range are considered acceptable for the near-term hydrodynamic studies planned for the facility.

STRUCTURAL VIBRATION SPECTRA

An accelerometer was glued at various circumferential positions on the outside pipe wall at station 7 to detect axial, lateral, and vertical vibrations. Spectra were obtained for each position of the accelerometer under test conditions of pump off, pump on but no flow, and mean nominal velocities of 4, 16, and 30 ft/sec.

As with the pressure spectra, the test conditions with the pump on had only negligible effect on the vibration spectra. Therefore, only spectra for the pump off case and the 16-ft/sec case are presented for each of the three vibration directions. These data are included in figures 8 through 13.

The spectra are plotted as dB//1 μg/Hz versus frequency, and each shows the spectra plotted for the 0-200, 0-500, and 0-10,000 Hz ranges. Each graph provides the same information as the pressure spectra.

Figure 10 shows the vertical vibration spectra for the pump off case. The upper spectrum shows a peak at 57.5 Hz caused by the air conditioner (located in the test room). The lower spectrum shows that this peak was eliminated by shutting off the air conditioner.

The largest vibrations were observed in the axial direction. Note that in figures 12 and 13 the scale of the abscissa has been increased by 20 dB. Overall, the vibration levels with the pump running were high and were noticeable by touching the test section.

Even though spectra were not obtained for locations downstream of the test section vibration isolator, it was very apparent by touching the pipe that the isolator was very effective in reducing the structural vibrations. Future testing needs to be conducted to determine whether the vibrations are introduced through the piping itself or up through the floor.

The vibration levels presented here will not affect the hydrodynamic studies to be conducted in the near future but will have to be reduced prior to making acoustic measurements.

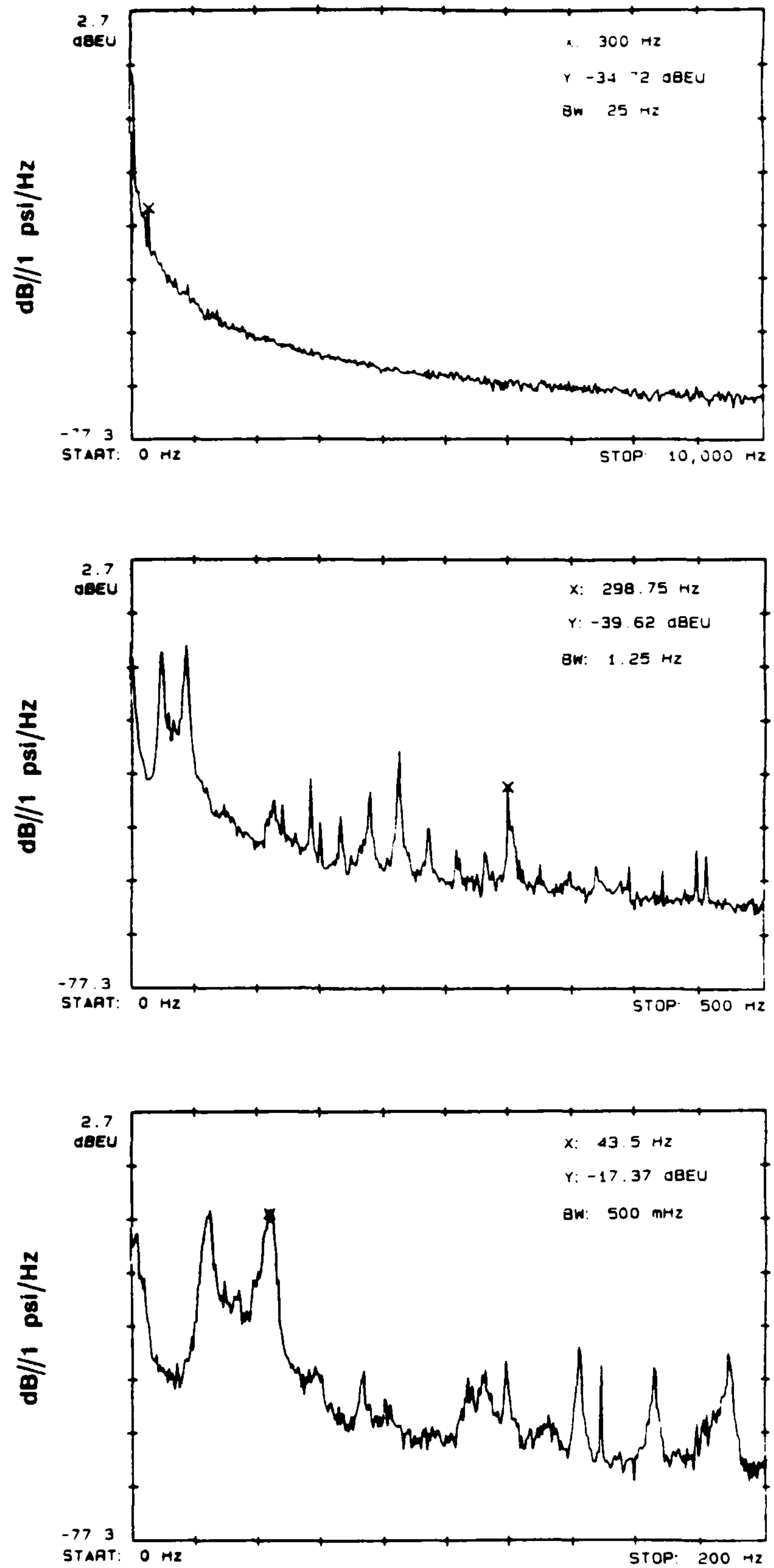


Figure 7. Pressure Spectra: 15.8-ft/sec Flow Velocity

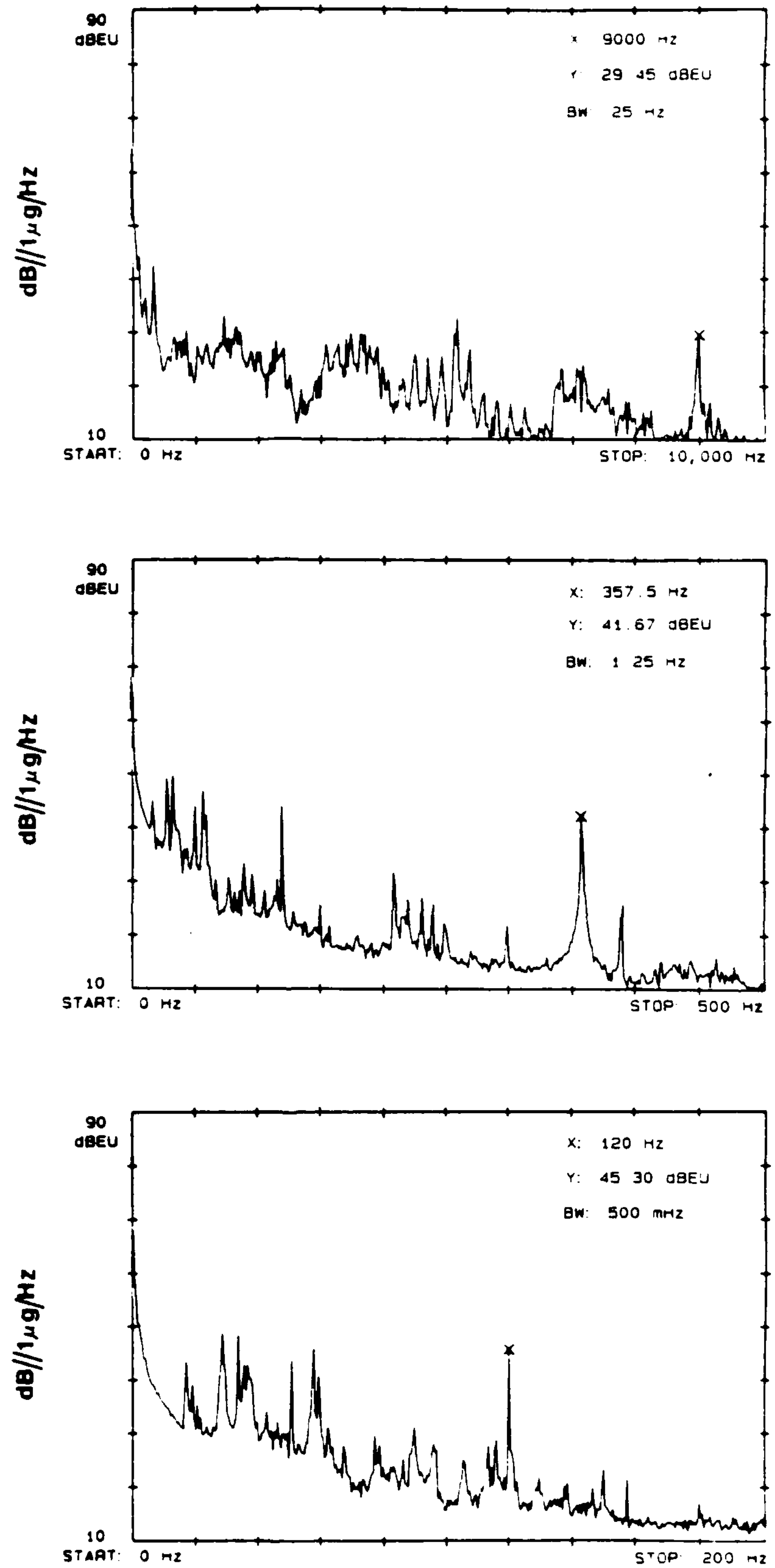


Figure 8. Lateral Vibration Spectra: Pump Off

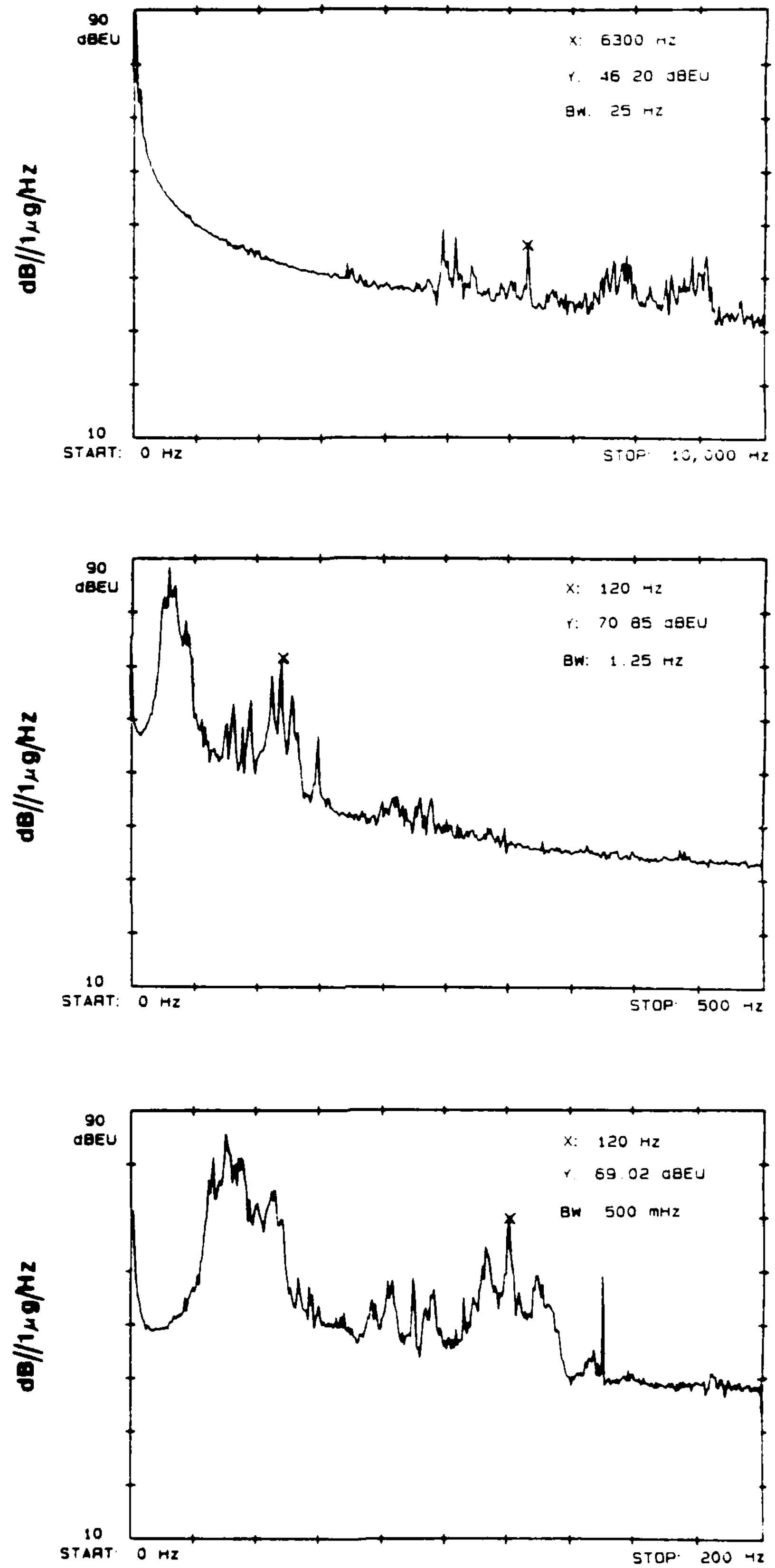


Figure 9. Lateral Vibration Spectra: 15.7-ft/sec Flow Velocity

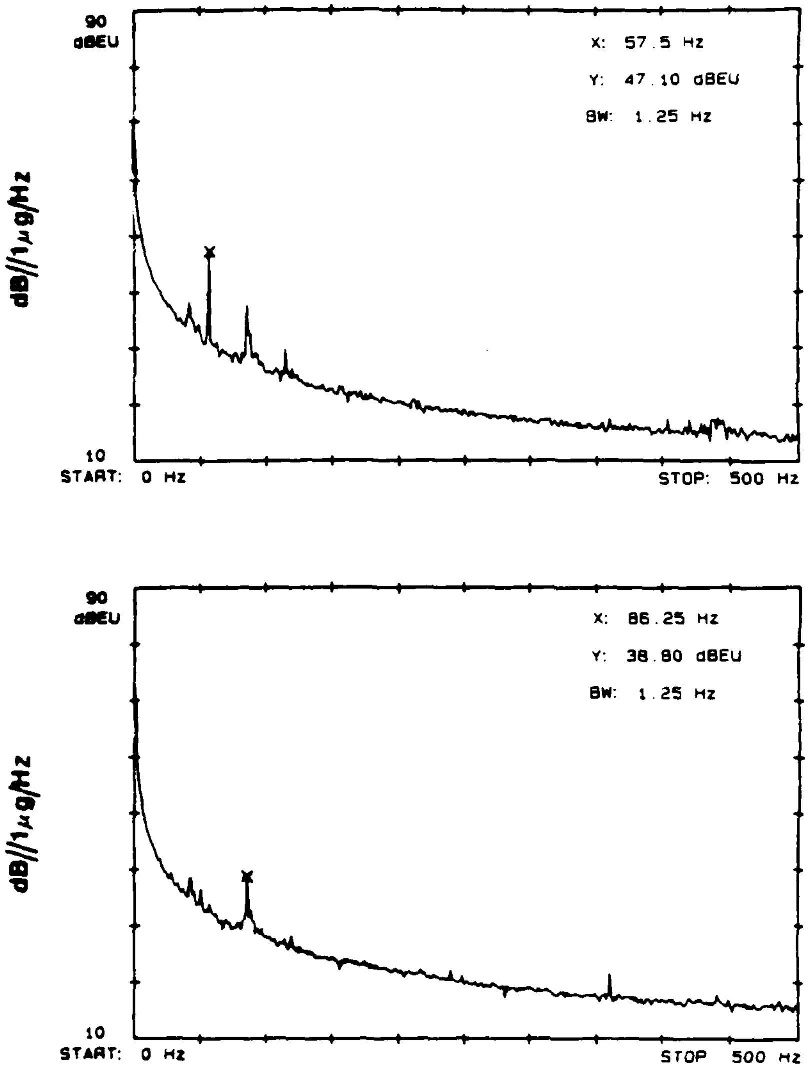
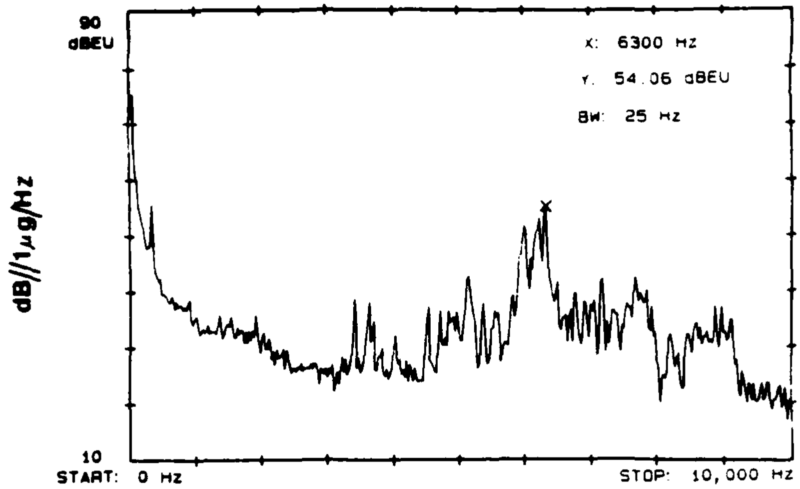
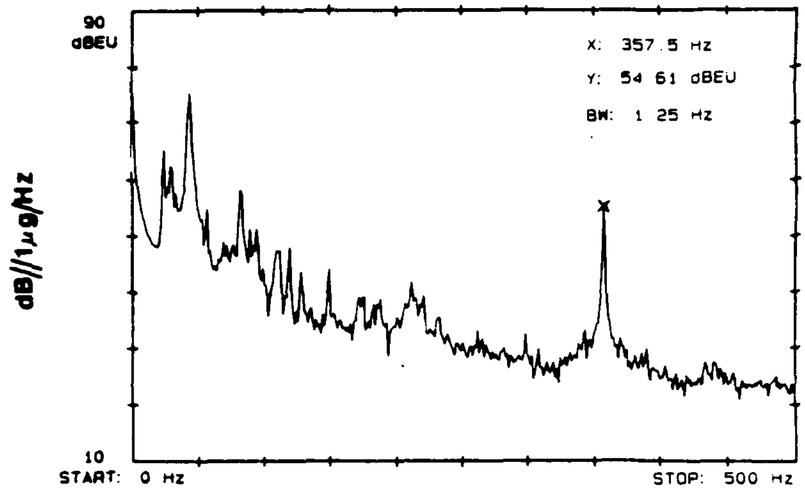


Figure 10. Vertical Vibration Spectra: Pump Off





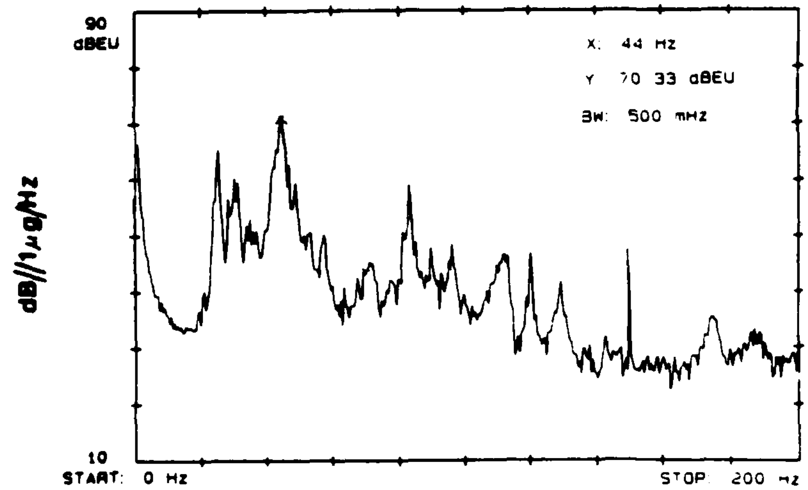


Figure 11. Vertical Vibration Spectra: 16.0-ft/sec Flow Velocity

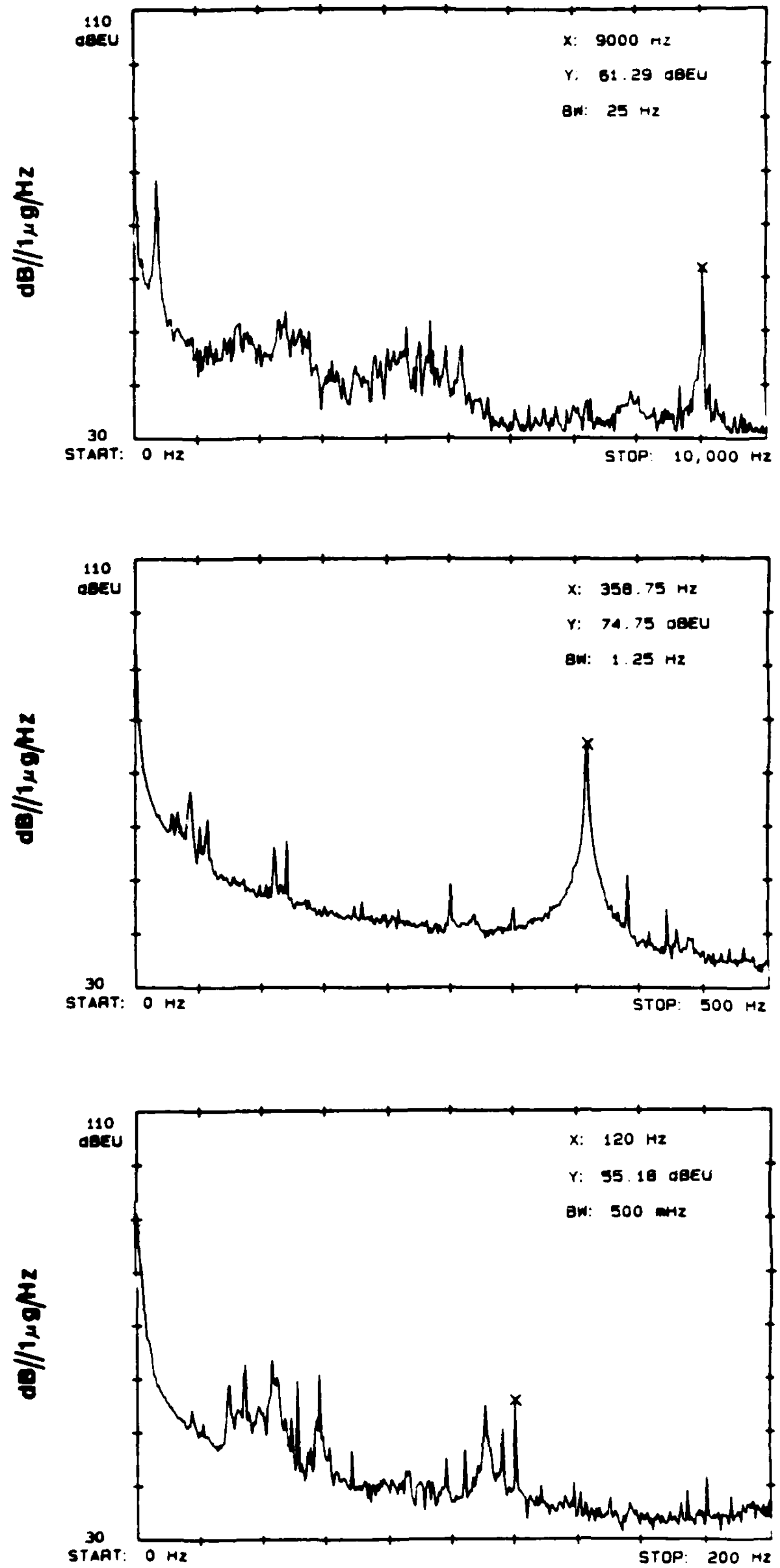


Figure 12. Axial Vibration Spectra: Pump Off

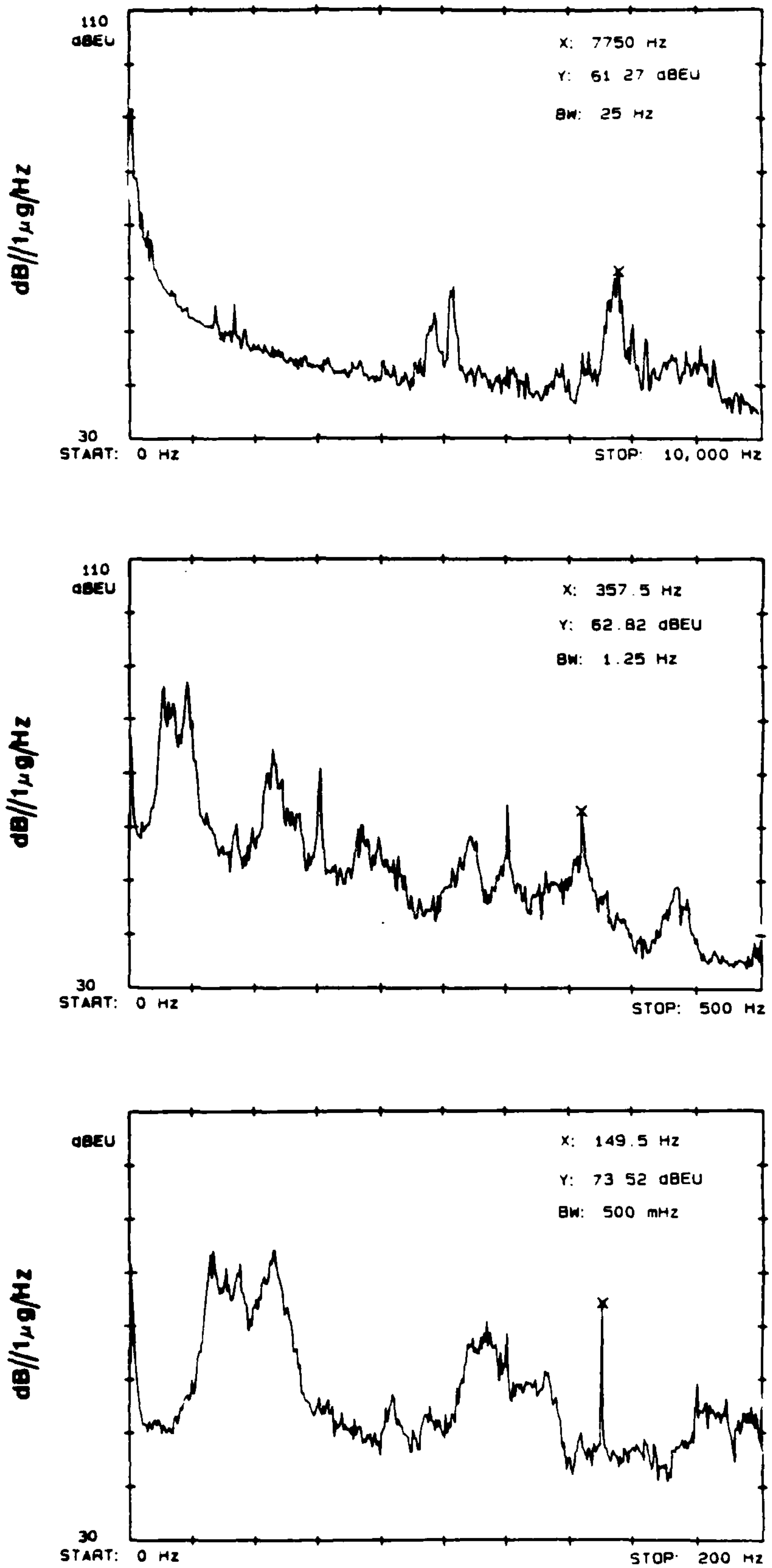


Figure 13. Axial Vibration Spectra: 15.8-ft/sec Flow Velocity

SUMMARY

A unique Flow Loop Facility capable of providing user-defined flow acceleration has been designed and built. In the initial evaluation of the facility, entrance turbulence intensities were somewhat higher than expected but were still low compared to those normally found in pipe flows. Structural vibrations were somewhat high and, although acceptable for the planned near-term hydrodynamic studies, will have to be reduced prior to making any acoustic measurements.

REFERENCES

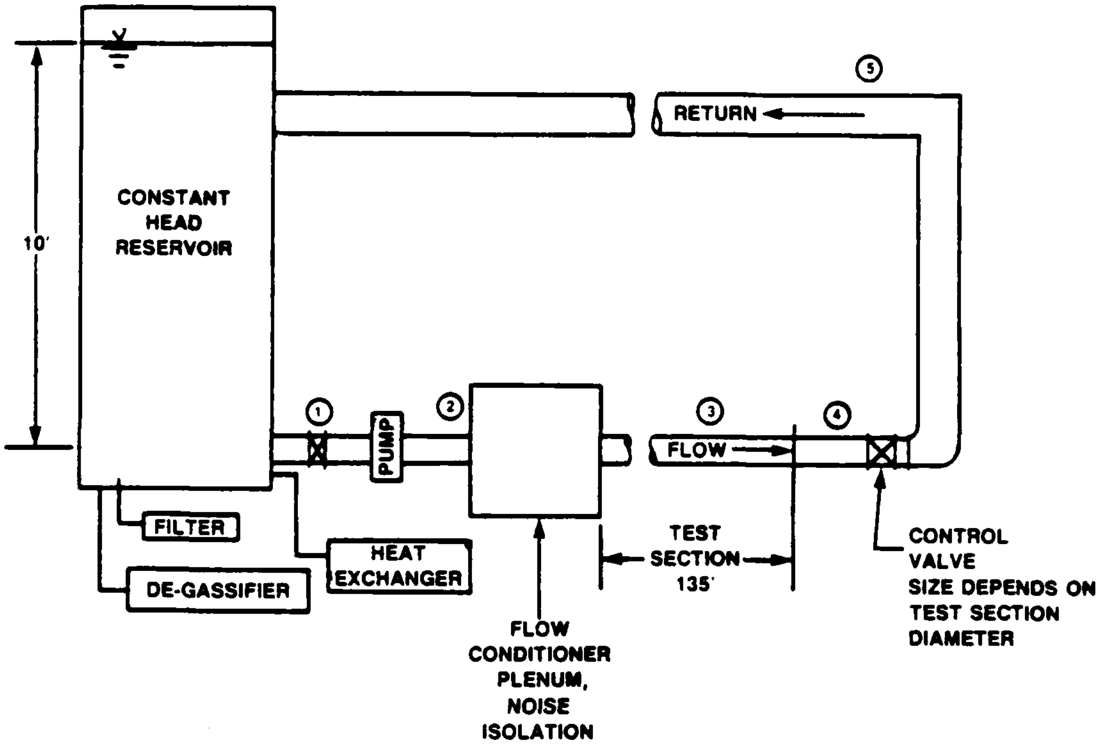
1. B.S. Stratford, "The Prediction of Separation of the Turbulent Boundary Layer," Journal of Fluid Mechanics, vol. 5, 1959.

2. J.L. Lumley and J.F. McMahon, "Reducing Water Tunnel Turbulence by Means of a Honeycomb," Journal of Basic Engineering, vol 89, December 1967.

3. P.J. Lefebvre and W.W. Durgin, "A Transient Electromagnetic Flowmeter," To be published at the ASME 1986 Winter Annual Meeting, December 1986, Anaheim, CA.

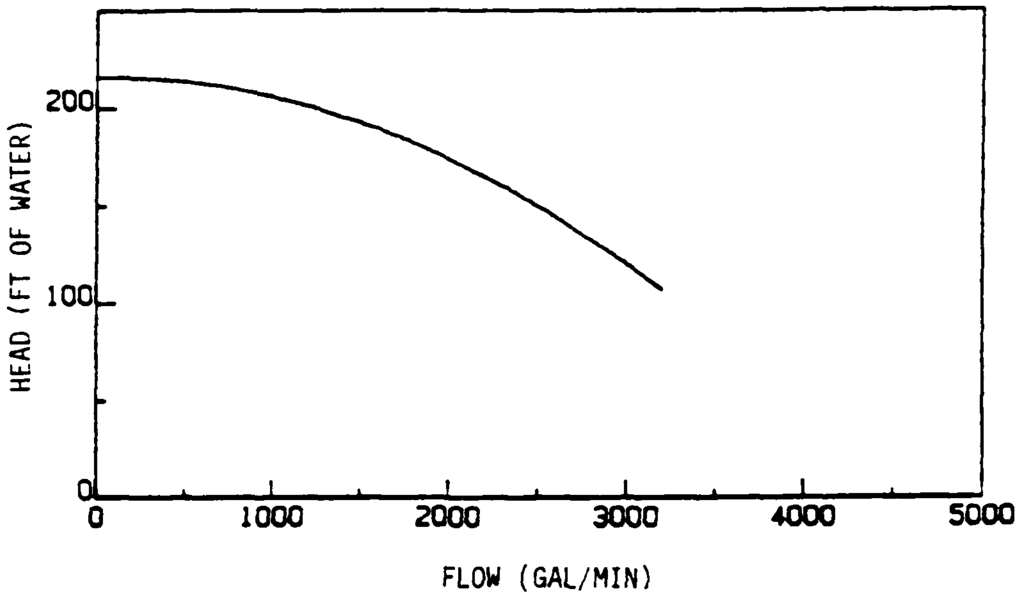
4. K.M. LaPointe and P.J. Lefebvre, "Flow Loop Facility Flow Control System," NUSC Technical Memorandum 85-2076, Naval Underwater Systems Center, Newport, RI, 15 November 1985.

APPENDIX
DESIGN DATA

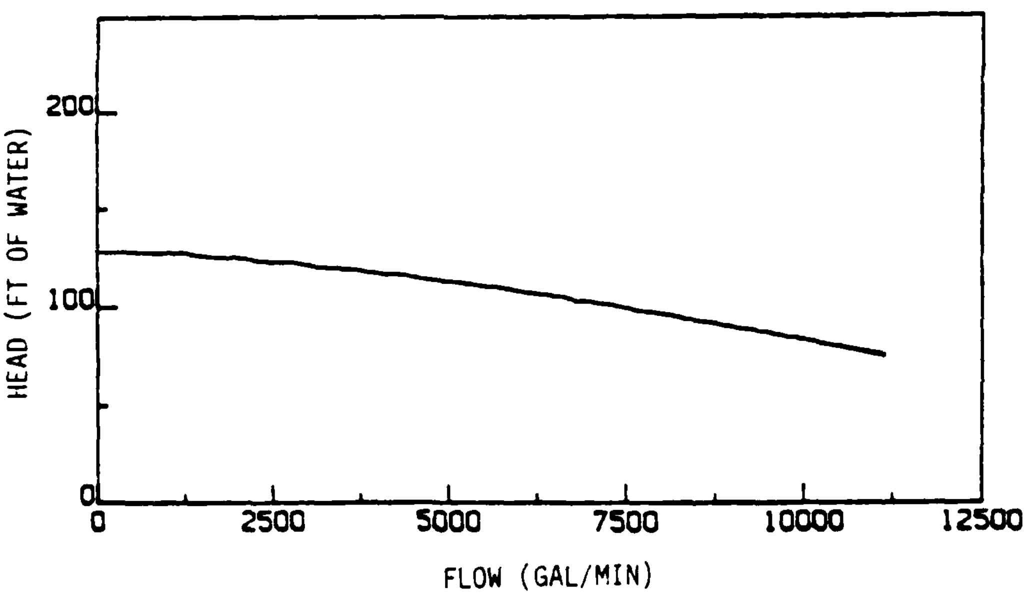


PIPE #	LENGTH (ft)	DIAMETER (inch)	WAVE SPEED (fps)	COEFF K FOR MINOR LOSSES
1	6	12	4200	0.3
2	6	12	4200	0.8
3	135	VARIABLE	4200	0.0
4	6	2, 4, 8 or 12	4200	0.5
5	150	18	1500	0.3

Figure A-1. Preliminary Conceptual Layout of Flow Loop Facility

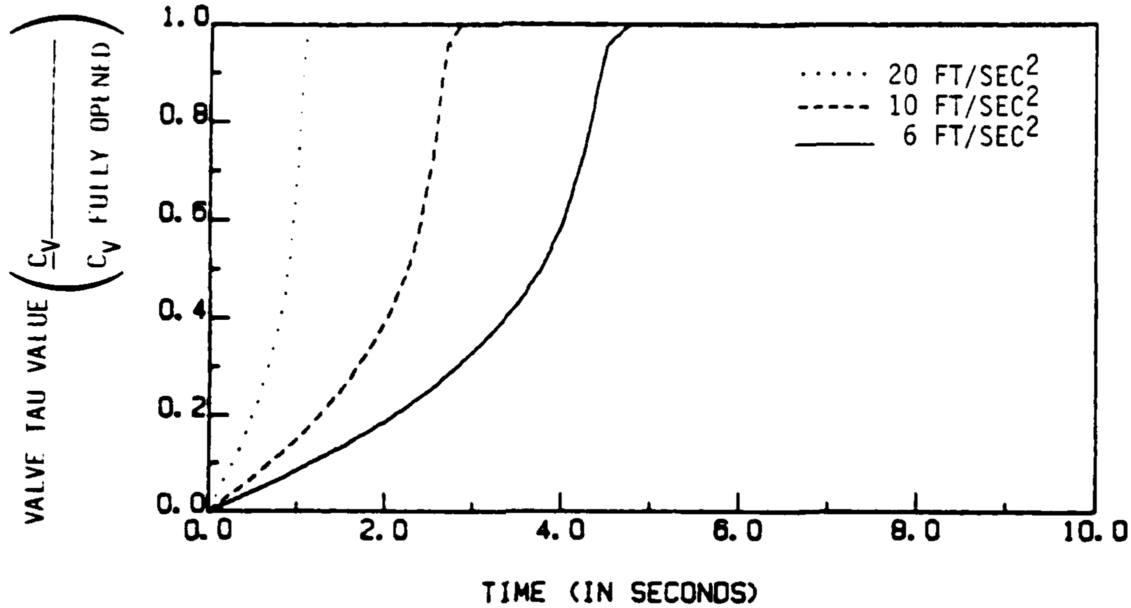


A. 150-HP Pump For Test Line Sizes of 6 Inches And Below



B. 300-HP Pump For Test Line Sizes Above 6 Inches

Figure A-2. Head Flow Curves for Selected Pumps



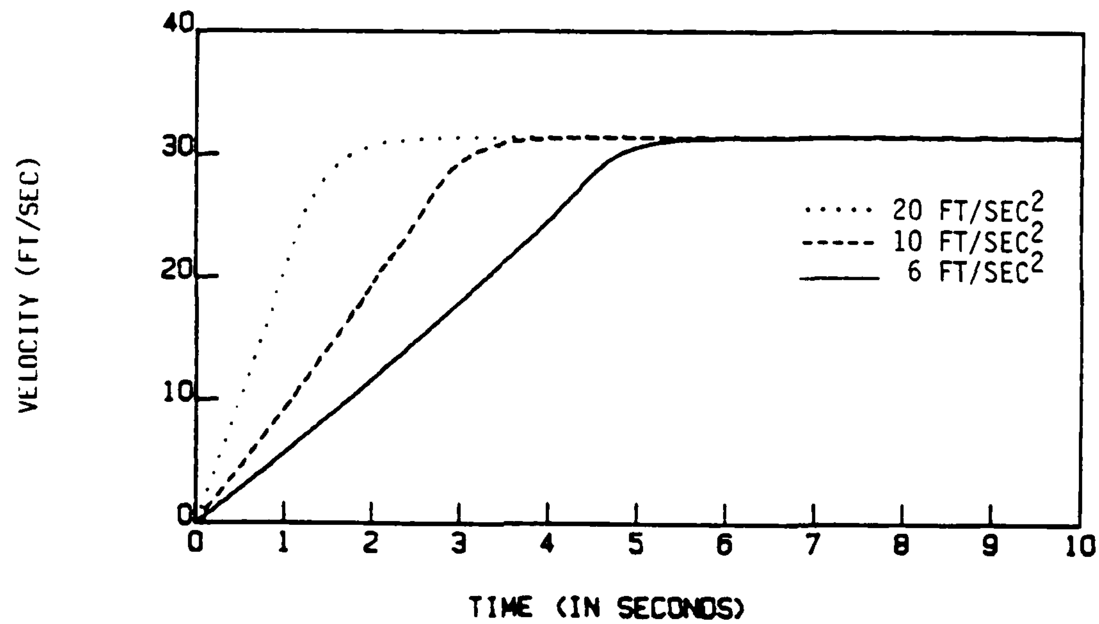
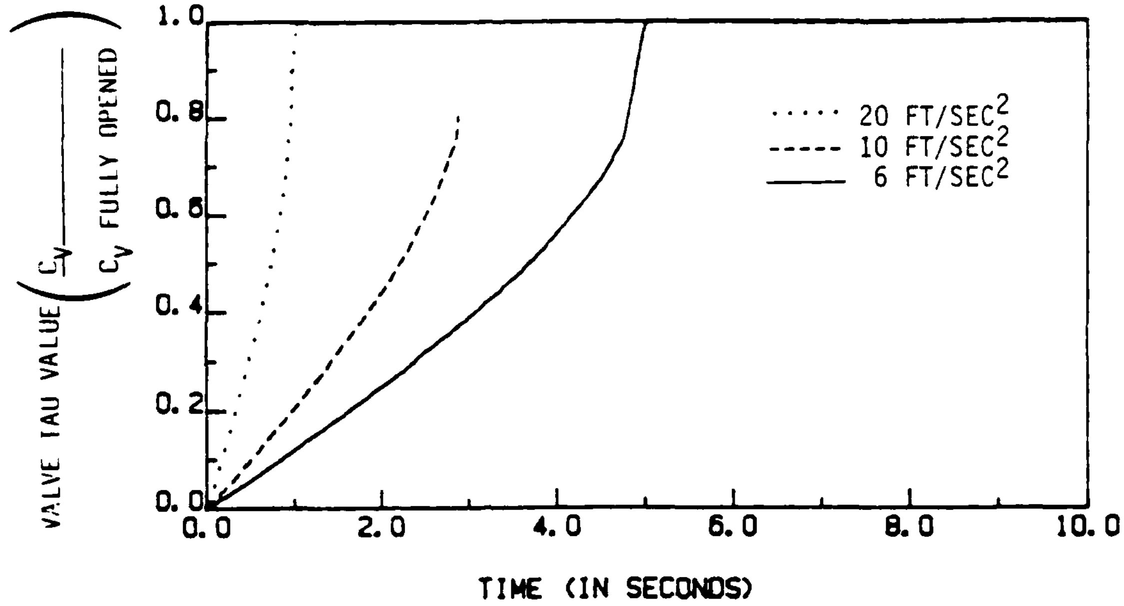


Figure A-3. Valve Opening Details for 2-Inch Test Pipe: C_V for Fully Open 2-Inch Valve = 75



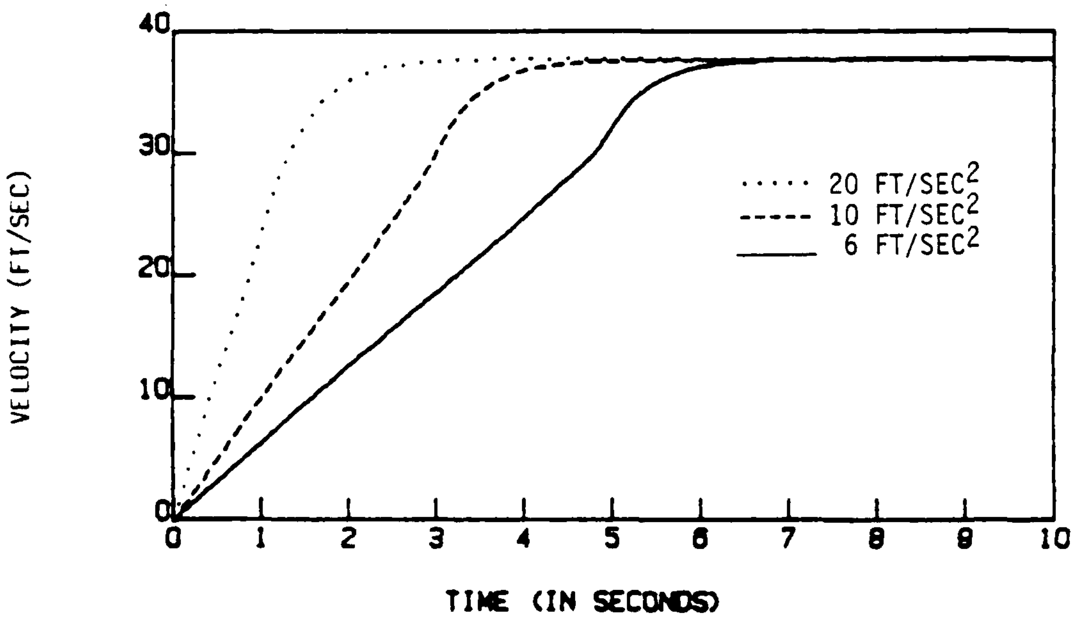
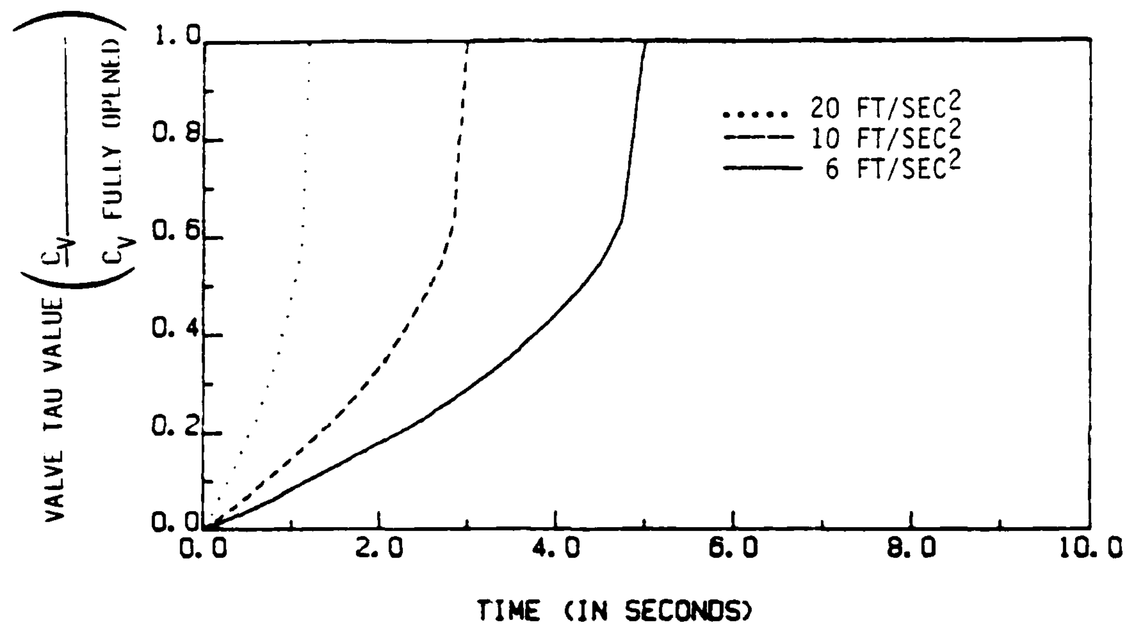


Figure A-4. Valve Opening Details for 4-Inch Test Pipe:
C_V for Fully Open 4-Inch Valve = 235



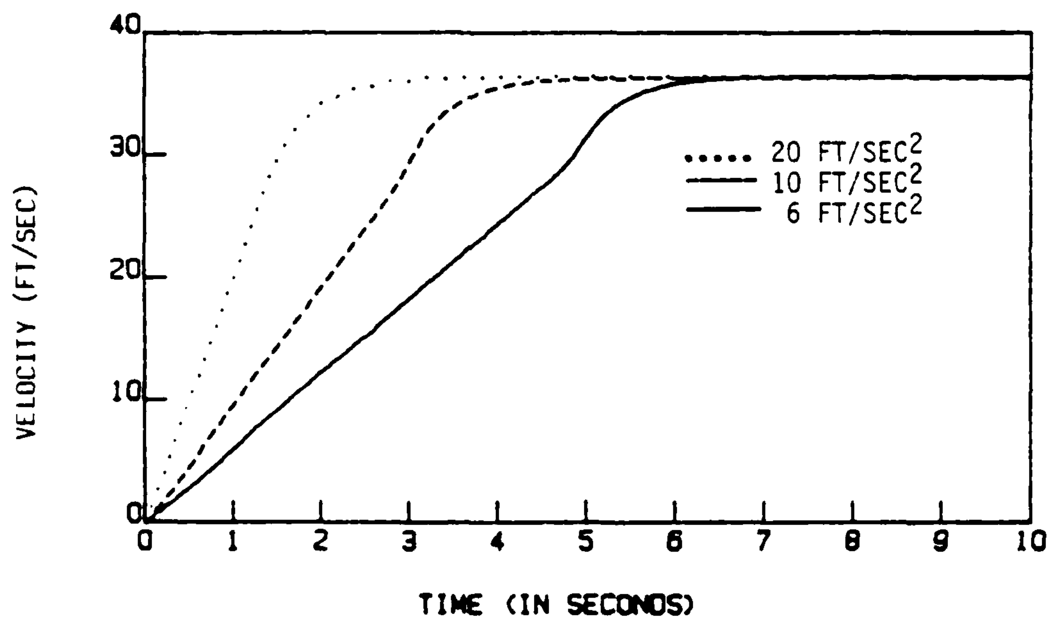
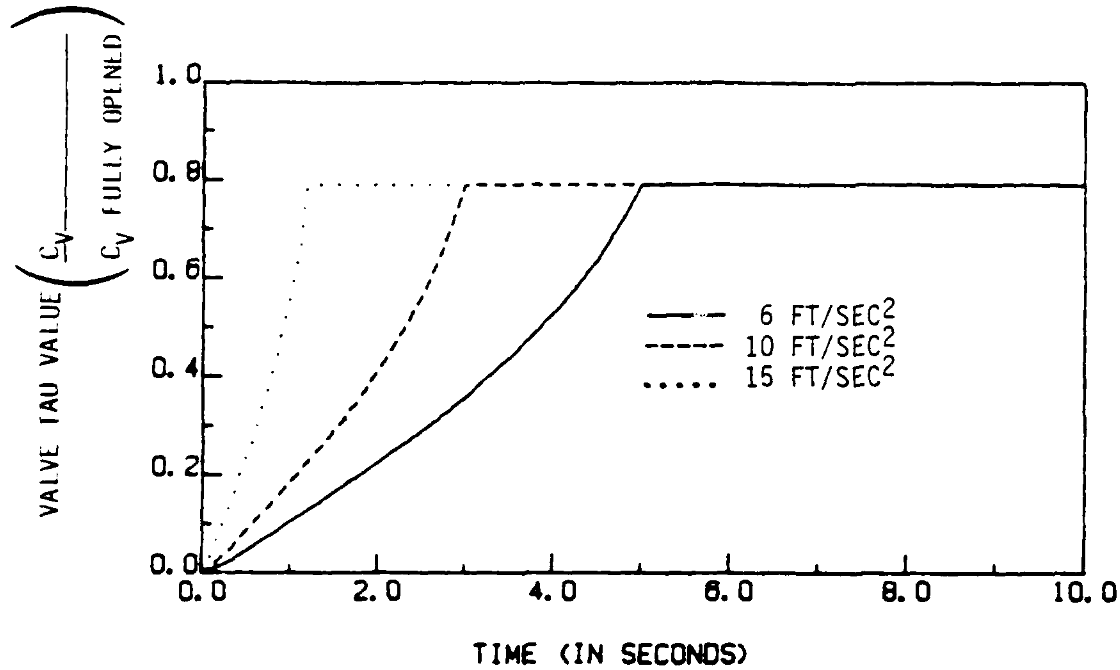


Figure A-5. Valve Opening Details for 6-Inch Test Pipe:
C_V for Fully Open 8-Inch Valve = 735



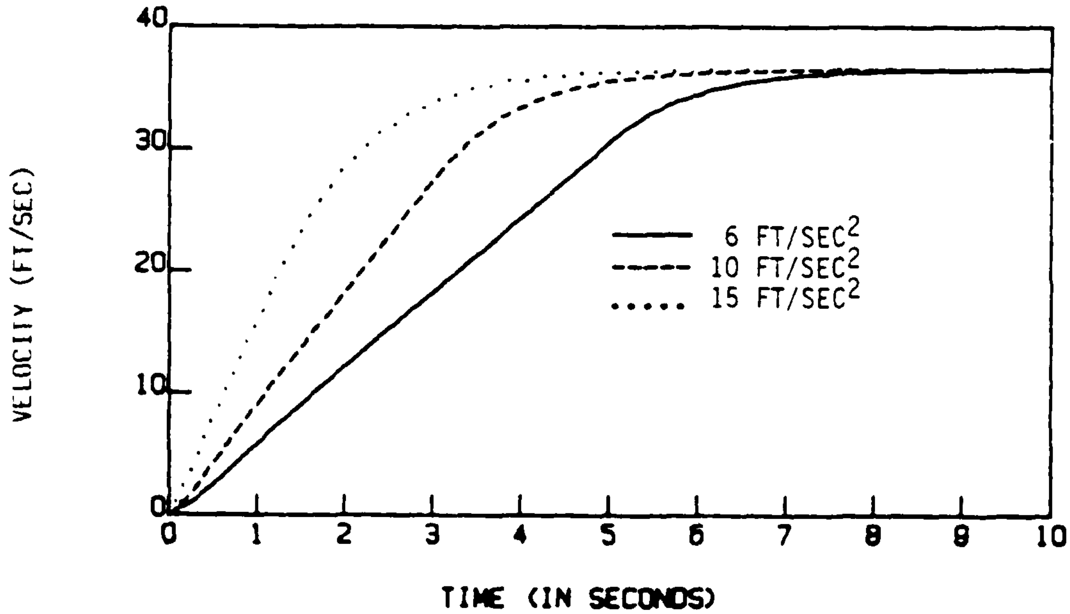
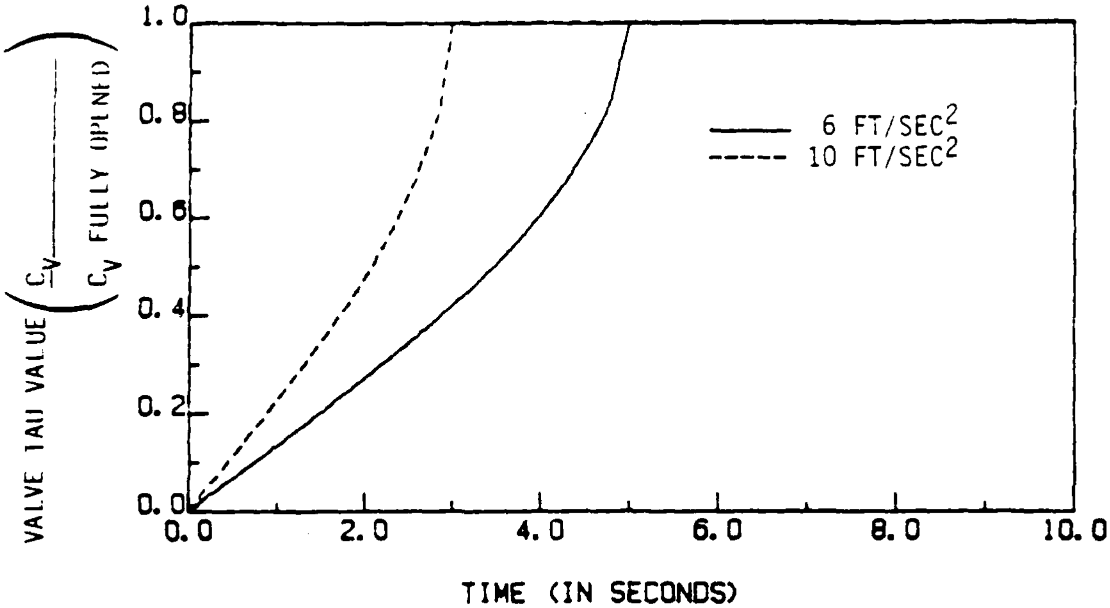


Figure A-6. Valve Opening Details for 8-Inch Test Pipe:
C_V for Fully Open 12-Inch Valve = 1450



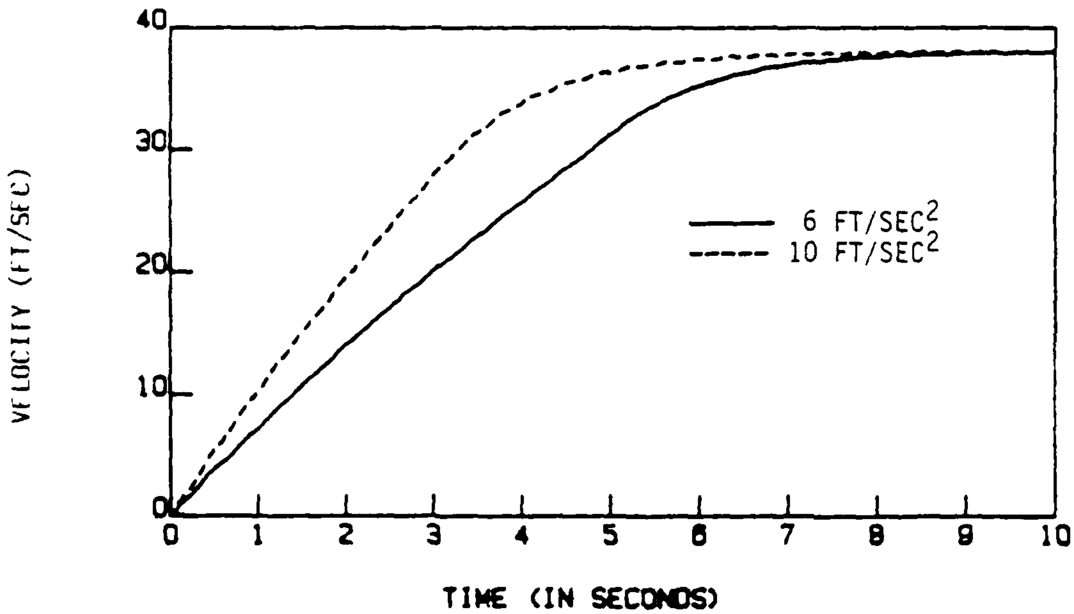


Figure A-7. Valve Opening Details for 10-Inch Test Pipe:
C_V for Fully Open 12-Inch Valve = 2360

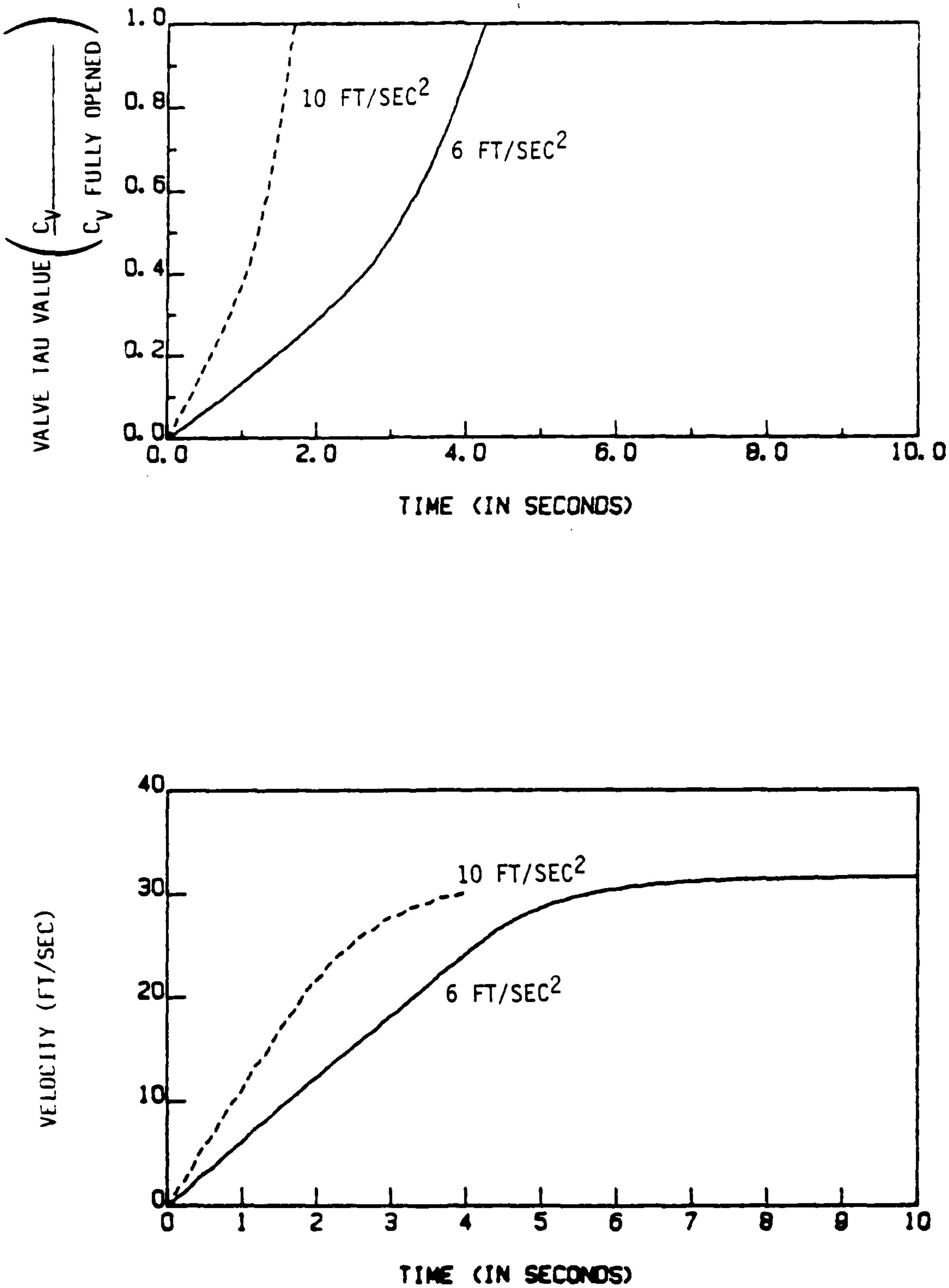
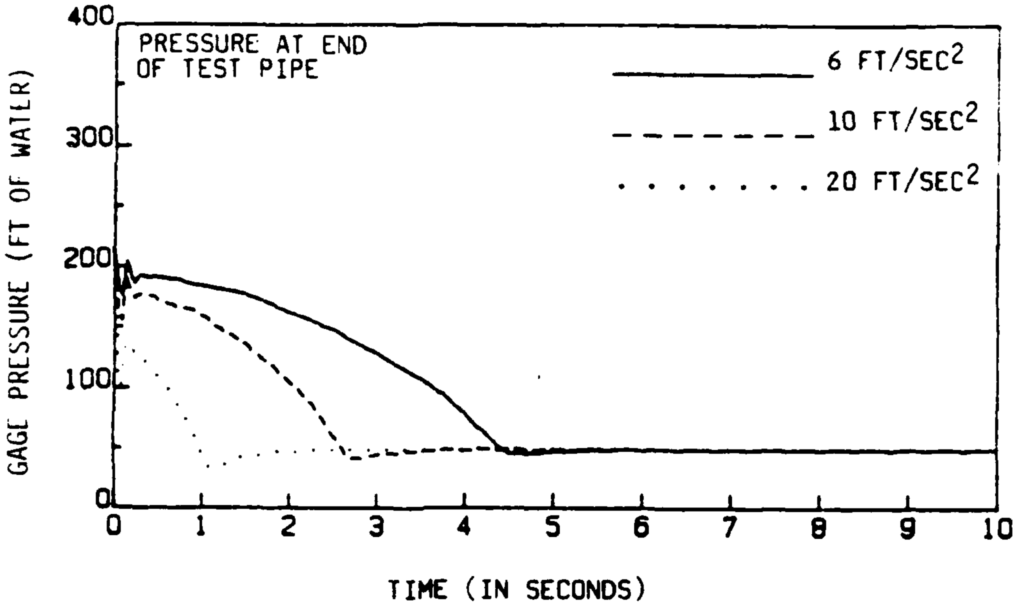


Figure A-8. Valve Opening Details for 12-Inch Test Pipe: C_V for Fully Open 12-Inch Valve = 2940



MAXIMUM & MINIMUM GAGE PRESSURES (FT OF WATER) IN PIPES

($6\ FT/SEC^2$)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.03	216.64	216.75	216.75	10.75
MINIMUM	9.91	215.87	45.53	45.04	9.72

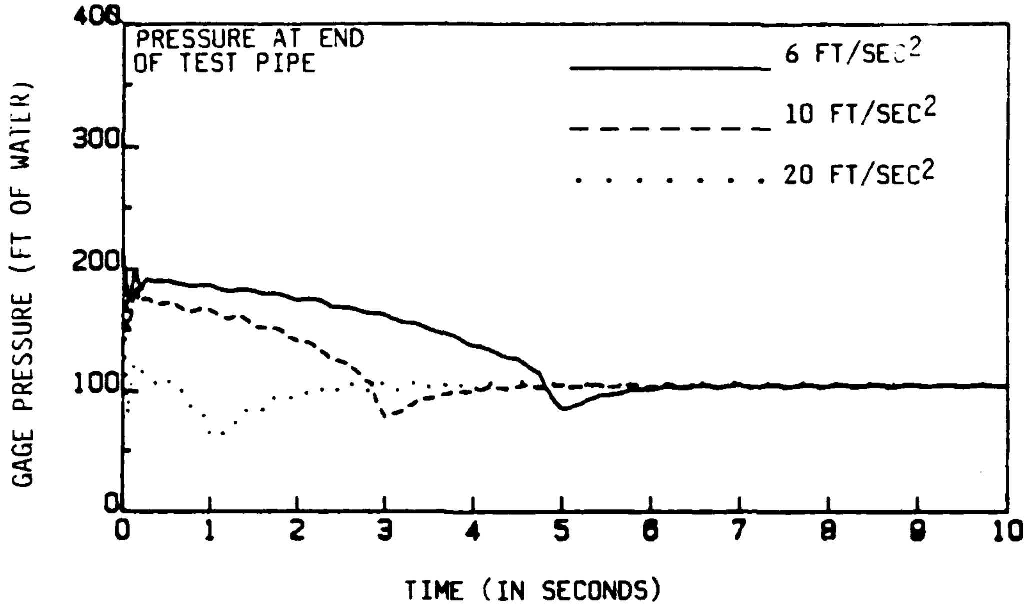
($10\ FT/SEC^2$)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.03	216.64	216.75	216.75	11.19
MINIMUM	9.86	215.87	42.13	41.50	9.58

($20\ FT/SEC^2$)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.01	216.63	216.75	216.75	12.36
MINIMUM	9.68	215.87	33.50	32.42	9.09

Figure A-9. Pressures for 2-Inch Test Section for Various Accelerations



MAXIMUM & MINIMUM GAGE PRESSURES (FT OF WATER) IN PIPES
(6 FT/SEC^2)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.08	216.77	216.96	216.69	13.73
MINIMUM	9.49	193.97	84.01	79.14	9.31

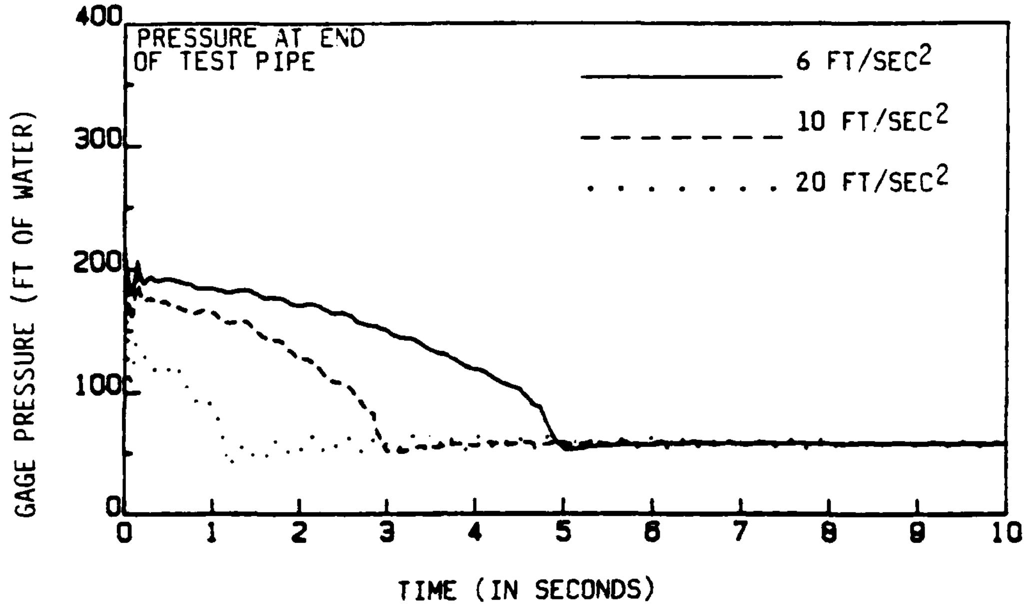
(10 FT/SEC^2)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.08	216.74	216.74	216.69	14.84
MINIMUM	9.17	193.57	77.79	72.26	8.91

(20 FT/SEC^2)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.02	216.62	216.69	216.69	20.64
MINIMUM	7.55	193.89	60.53	54.63	6.32

Figure A-10. Pressures for 4-Inch Test Section for Various Accelerations



MAXIMUM & MINIMUM GAGE PRESSURES (FT OF WATER) IN PIPES
(6 FT/SEC^2)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.18	216.81	216.81	216.63	16.58
MINIMUM	9.08	106.23	52.67	48.72	9.79

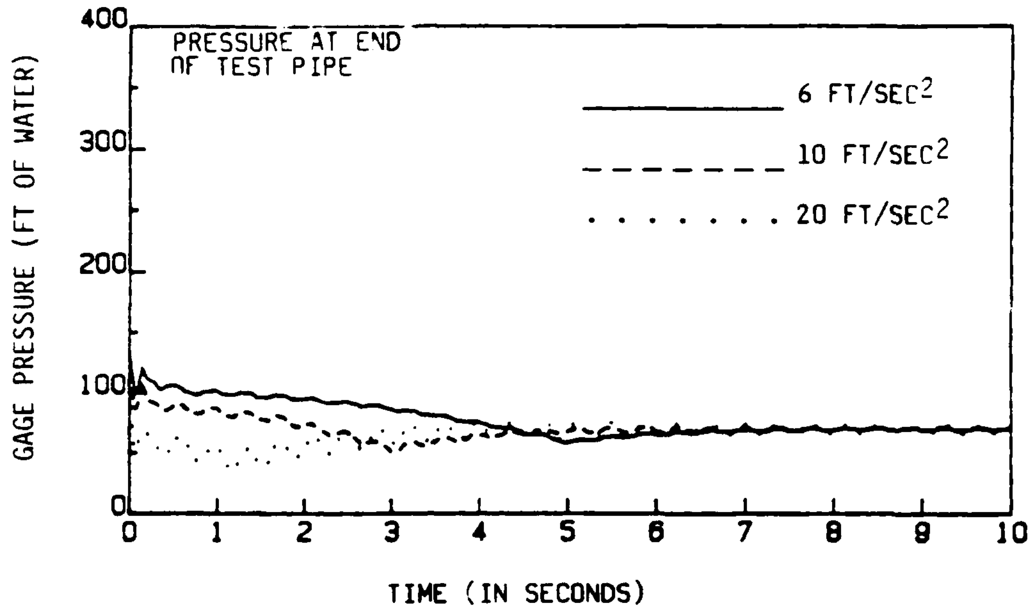
(10 FT/SEC^2)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.22	216.81	216.78	216.63	19.27
MINIMUM	8.68	106.25	51.04	47.19	9.28

(20 FT/SEC^2)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.01	216.61	216.63	216.63	29.42
MINIMUM	6.81	105.80	38.23	34.47	3.87

Figure A-11. Pressures for 6-Inch Test Section for Various Accelerations



MAXIMUM & MINIMUM GAGE PRESSURES (FT OF WATER) IN PIPES

($6\ FT/SEC^2$)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.25	132.12	132.12	132.01	18.76
MINIMUM	7.98	110.81	57.75	55.71	9.56

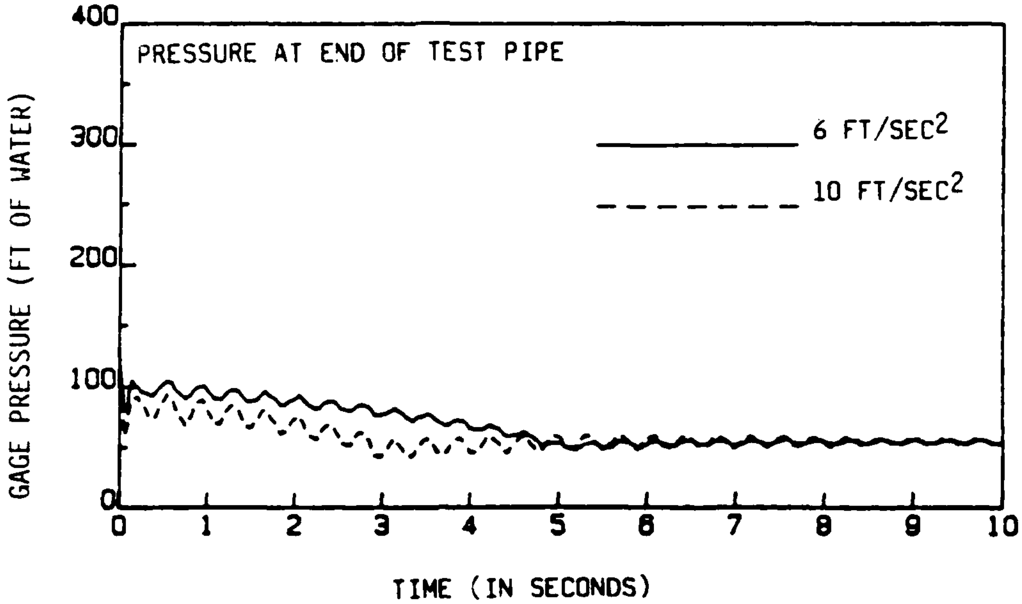
($10\ FT/SEC^2$)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.13	132.00	132.01	132.01	18.76
MINIMUM	7.90	110.69	50.50	48.52	9.56

($20\ FT/SEC^2$)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.01	132.00	132.01	132.01	36.66
MINIMUM	6.06	110.54	33.18	31.39	3.83

Figure A-12. Pressures for 8-Inch Test Section for Various Accelerations



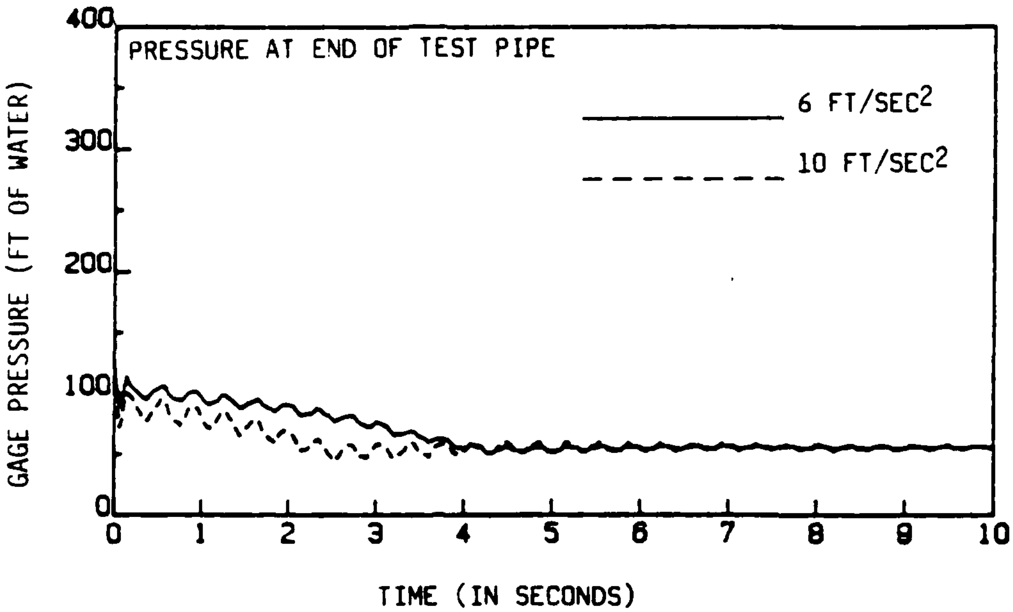
MAXIMUM & MINIMUM GAGE PRESSURES (FT OF WATER) IN PIPES
($6\ FT/SEC^2$)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.01	132.00	132.01	132.01	32.19
MINIMUM	5.55	88.77	47.22	42.12	8.71

($10\ FT/SEC^2$)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.01	132.00	132.01	132.01	40.89
MINIMUM	5.22	88.18	40.09	35.31	7.00

Figure 13. Pressures for 10-Inch Test Section for Various Accelerations



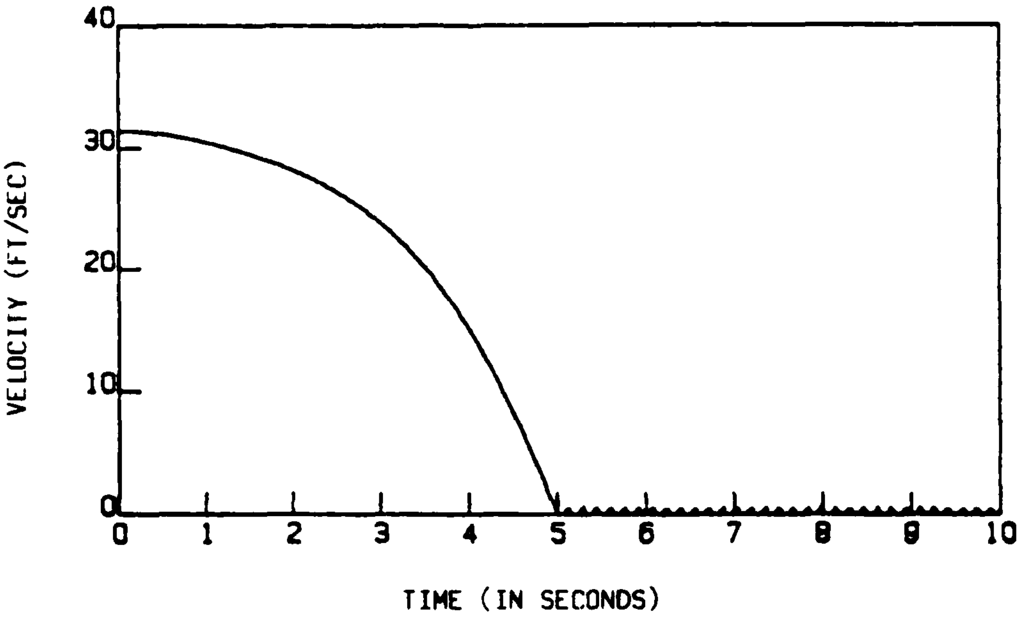
MAXIMUM & MINIMUM GAGE PRESSURES (FT OF WATER) IN PIPES
($6\ FT/SEC^2$)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.01	132.00	132.01	132.01	33.98
MINIMUM	4.01	75.00	49.49	42.78	9.55

($10\ FT/SEC^2$)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.01	132.00	132.01	132.01	44.67
MINIMUM	3.91	74.70	44.12	38.13	8.40

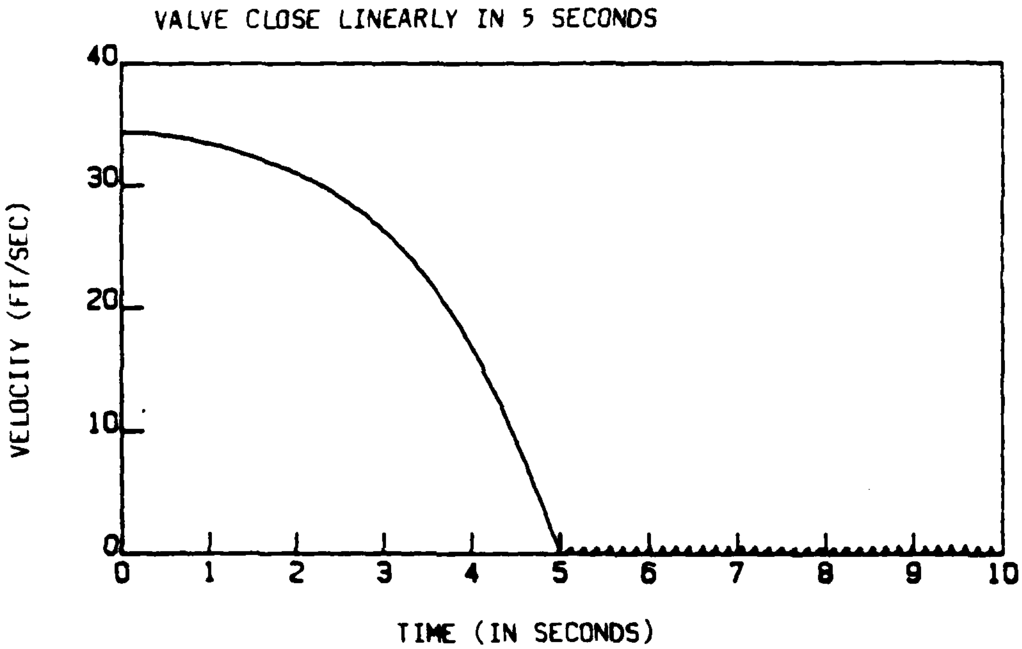
Figure A-14. Pressures for 12-Inch Test Section for Various Accelerations



MAXIMUM & MINIMUM PRESSURES IN PIPES
(FT OF WATER)

PIPE NO.	1	2	3	4	5
MAXIMUM	10.39	217.26	287.67	288.45	110.98
MINIMUM	9.60	215.88	48.96	48.70	9.02

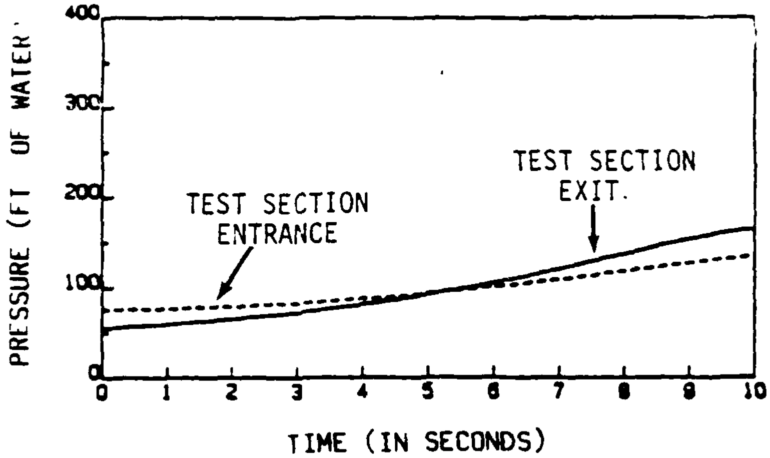
Figure A-15. Maximum and Minimum Pressures with 2-Inch Test Section and a 5-Second Valve Closure; Linear Variation of C_V Assumed



MAXIMUM & MINIMUM PRESSURES IN PIPES
(FT OF WATER)

PIPE NO.	1	2	3	4	5
MAXIMUM	12.04	220.28	303.98	304.81	19.89
MINIMUM	7.94	117.75	53.28	49.75	0.07

Figure A-16. Maximum and Minimum Pressures with 6-Inch Test Section and a 5-Second Valve Closure; Linear Variation of C_V Assumed



MAXIMUM & MINIMUM PRESSURES IN PIPES
(FT OF WATER)

PIPE NO.	1	2	3	4	5
MAXIMUM	11.97	135.88	165.27	166.62	25.01
MINIMUM	4.34	75.38	55.45	46.82	-5.18

Figure A-17. Maximum and Minimum Pressures with 12-Inch Test Section and 10-Second Valve Closure; Linear Variation of C_V Assumed

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